DEVELOPMENT AND EVALUATION OF FLY ASH SAND COMPOSITE MATERIALS WITH ADDITIVES

thesis submitted in partial fulfillment of the requirement for the degree of

Master of Technology

in

MINING ENGINEERING

by

Vivek Kumar Kashi
[Roll No - 213MN1492]

DEPARTMENT OF MINING ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY,
ROURKELA – 769 008
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CERTIFICATE

This is to certify that the thesis entitled "D**evelopment and Evaluation of Fly Ash Sand Composite Materials with Additives**" Submitted by **Vivek Kumar Kashi,** Roll No. 213MN1492 to National Institute of Technology, Rourkela for the award of the degree of M.Tech.in Mining engineering, is a record of bonfire research work under my supervision and guidance. The research scholar has fulfilled all prescribed requirements for the thesis, which is based on his own work and the thesis my opinion, is worthy of consideration for the award of degree of Master of Technology of the Institute. The result reported in this thesis has not been submitted to any other University/Institute for the award of any other degree or diploma.

Date:

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Abstract

The Coal production in India 2013-14 was 565.64 Million tons compared to 556.41 Million tons (MT) during the 2012-13. The coal deposit of India has high ash content of the order of 30 -45%, hence produces lot of ash when burnt. The use of fly ash has increased from 6.64 million ton in 1996-97 to a level of 99.62 million-ton in the year 2013-14. The use of fly ash is 57.63% during 2013-14. The harmless dumping of the fly ash is a major problem for the environment. Huge area required for the storage that are main challenges for sustainable development. A new invention and researches are going on for the bulk usage of fly ash. Now the use of fly ash in the bulk mode is applicable in the field of geotechnical engineering applications such that brick manufacturing, structural fills, filling of mines, production of embankments, construction of roads, haul roads etc.

An effort has been made in this investigation to assess the potential utilization of fly ash composite material made by mixing of fly ash, sand, and cement or lime. In this report, a comparison study have been carried out with the two additives cement and lime in the fly ash. The leading constituents of the composite are Fly Ash, Sand, and Cement or Lime. Different percentage of fly ash samples i.e. 85, 75, and 65 are taken with different percentages of cement or lime i.e. 3, 5, and 8 with sand of 12, 20 and 27% and their properties are studied. Various geotechnical experiments are carried out on the fly ash samples. Those are Brazilian Tensile Strength Test (BTS), Unconfined Compressive Strength Test (UCS), Direct Shear Strength Test (DSS) and Ultrasonic Pulse Velocity Test (UPV).

Tensile strength, Compressive strength, Shear strength, Optimum moisture content (OMC), Cohesion, Internal Friction angle, Maximum dry density, static and dynamic Poisson Ratio are determined from the fly ash composite materials after 0, 7, 14, 28, 56 and 90 days of curing period. Lime and cement % have maximum bearing on the fly ash composite material through with varying magnitude. Fly ash gains strength in the presence of additives.

Keywords: - Fly Ash, Cement, Lime, Sand, Strength

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LIST OF SHORTENINGS:

FCM	Fly Ash Composite Material
BTS	Brazilian Tensile Strength
UCS	Unconfined Compressive Strength
DSS	Direct Shear Strength
UPV	Ultrasonic Pulse Velocity
OMC	Optimum Moisture Content
PR	Poisson Ratio
IFA	Internal Friction Angle
MDD	Maximum Dry Density
PL	Plastic Limit
MC	Moisture Content

CHAPTER 1
INTRODUCTION

1.1Background:

To become the India as a developed country, its priority is to be establishing a long-term development and maintenance plan, enormous power resources are needed to meet its goal by 2025. Coal is the world's most widely and mostly used fossil fuel. So, wherever power is required, each and every sector of the industry, mostly coal is used. In India, the thermal power plants generated about 760675.80 million units of power [1]. The Coal production in India 2013-14 was 565.64 Million tons compared to 556.41 Million tons (MT) during the 2012-13 and showed a growth rate of 1.7 (%) percent. Out of which, 500.05 MT coal is used for power generation [2]. The production of electricity in the country is and would continue coal based in the near future predominantly. At present fly ash is a compulsory byproduct of coal combustion from the thermal power plant and other industry when coal is used as a fuel. This production of the fly ash requires an enormous land area and has an adverse impact on the environment. These days, some amount of fly ash used in different industries like Road Subbase , Grout, Brick, Embankment/ Structural Fill, Portland Cement and Mine Reclamation, Soil Stabilization, Waste Stabilization and Solidification, Aggregate, Numerous Agricultural Applications etc.

The coal of India is having high ash content of the order of 30 -45% [3]. The utilization of fly ash has increased from 6.64 million ton in 1996-97 to a level of 99.62 million-ton in the year 2013-14. The use of fly ash is 57.63% during 2013-14 [3].

Table-1: Projected Coal Demand (Million Tons) [4]

Sector	2011-12	2016-17	2021-22	2026-27	2031-32
Electricity	539	836	1,040	1,340	1,659
Iron & Steel	69	104	112	120	150
Cement	32	50	95	125	140
Others	91	135	143	158	272
Total	731	1,125	1,390	1,743	2,221

TABLE-2: GENERATION OF FLY ASH AND ITS UTILIZATION DURING 1996-97 TO 2013-14 [5]

SL. No.	YEAR	Generation of Fly Ash (Million-ton)	Utilization of Fly Ash (Million-ton)	Utilization of Fly Ash (%)
1	1996-97	68.88	6.64	9.63
2	1997-98	78.06	8.43	10.8
3	1998-99	78.99	9.22	11.68
4	1999-2000	74.03	8.91	12.03
5	2000-01	86.29	13.54	15.7
6	2001-02	82.81	15.57	18.8
7	2002-03	91.65	20.79	22.68
8	2003-04	96.28	28.29	29.39
9	2004-05	98.57	37.49	38.04
10	2005-06	98.97	45.22	45.69
11	2006-07	108.15	55.01	50.86
12	2007-08	116.94	61.98	53
13	2008-09	116.69	66.64	57.11
14	2009-10	123.54	77.33	62.6
15	2010-11	131.09	73.13	55.79
16	2011-12	145.41	85.05	58.48
17	2012-13	163.56	100.37	61.37
18	2013-14	172.87	99.62	57.63

TABLE-3: GENERATION OF FLY ASH AND UTILIZATION IN THE YEAR 2013-14 [3]

Description	Year 2013-14
Nos. of Thermal Power Stations from which data was received	143
Installed capacity (MW)	1,33,381.30
Coal consumed (Million tons)	523.52
Fly Ash Generation (Million tons)	172.87
Fly Ash Utilization (Million tons)	99.62
Percentage Utilization	57.63
Percentage Average Ash Content (%)	33.02

TABLE-4: WAYS OF FLY ASH UTILIZATION IN THE YEAR 2013-14 [3]

Sl. No.	Mode of utilization	Quantity of Fly Ash utilized in the mode of utilization	
		Million-ton	Percentage (%)
1	Cement	39.17	39.32
2	Bricks & Tiles	12.23	12.27
3	Reclamation of low lying area	11.75	11.79
4	Mine filling	11.20	11.24
5	Ash Dyke Raising	10.32	10.36
6	Roads & flyovers	4.98	5.00
7	Agriculture	2.88	2.89
8	Concrete	0.91	0.92
9	Others	6.19	6.22
	Total	99.62	100

1.2 Aim and Objectives:

The aim of the investigation was to improve upon the usage of fly ash by using additives like cement and lime. Following were the specific objectives-

1. Detail study of Characterization of the fly ash and its utilization.
2. Preparation and development of composite materials with fly ash, sand, cement and lime.
3. Determination of various geotechnical properties like Unconfined Compressive Strength (UCS), Brazilian Tensile Strength (BTS), Direct Shear Test and Non Destructive Test (NDT).
4. A comparative study of additives used in the fly ash composite.

1.3 Methodology:

The aim and objective was achieved by following a step by step approach (fig. 1).

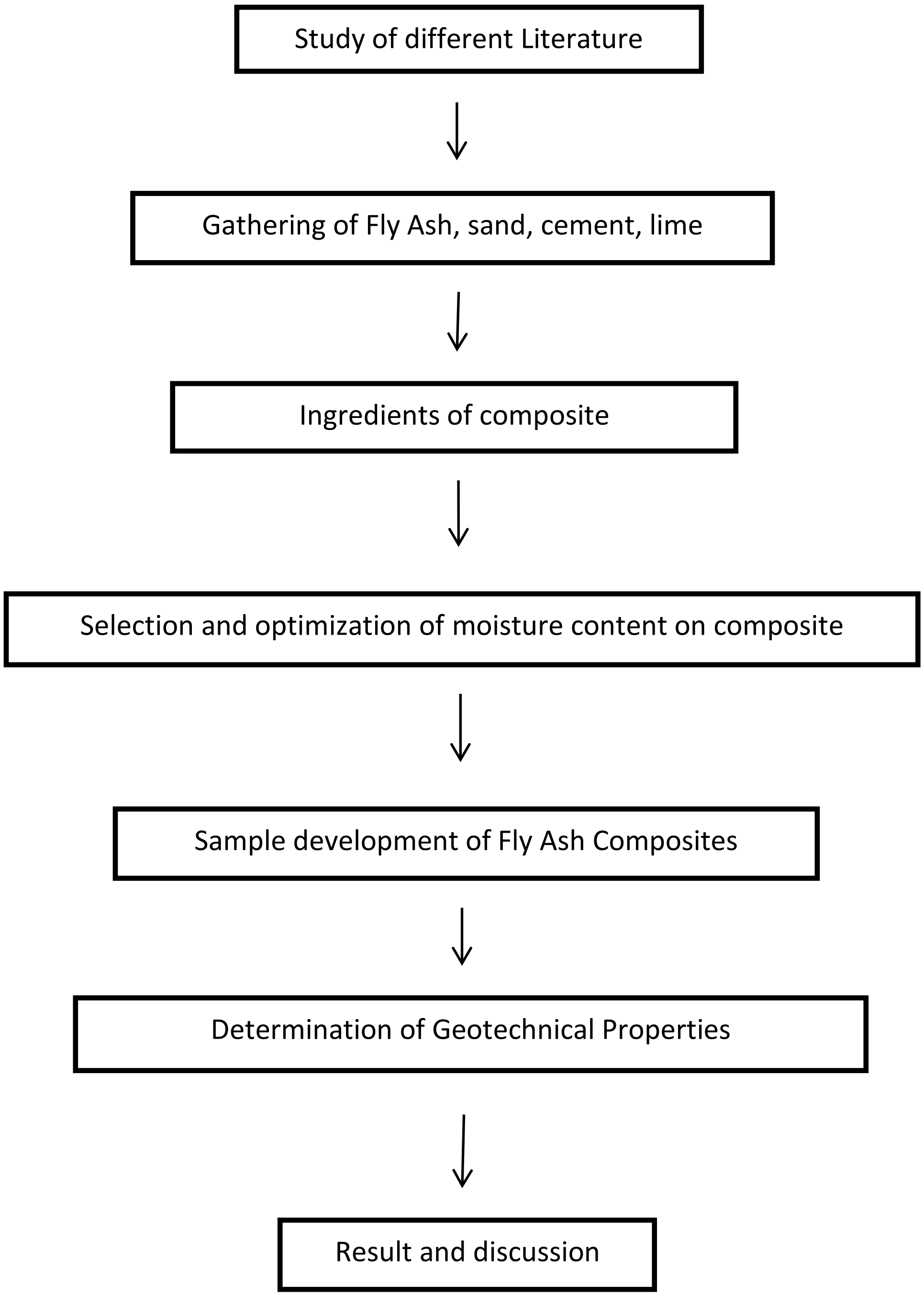

Fig. 1; Flow chart for methodology

1.4 Organisation of thesis:

There are six chapters in this thesis. The 1st chapter specifies the background, flow chart, aim and objectives. The 2nd chapter deals with the literature review on fly ash composite material and geotechnical properties of fly ash. The 3rd chapter gives a detailed study of materials and methods of investigation. It includes collection of ingredients and sample preparation. The 4th chapter includes a detailed procedure of different geotechnical experiments. The 5th chapter deals with results and discussion of geotechnical properties of fly ash composite material. It includes the variation of BTS, UCS, DST and USV with % of cement and lime additives and also with respect to curing period. The 6th chapter focuses on the conclusion of investigation. At the end, reference and Annexure are given.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction:

The third leading producer of coal and has the fourth largest reserves of coal in the world is India, which is approximately 197 billion tons [6]. The consumption of fly ash is about 57.63% during the year of 2013-14. The harmless dumping of the fly ash is a major problem for the environment. A huge area required for the storage that are main challenges for sustainable development. The dumping area of fly ash would need 1000 km2. Therefore, efforts are being constantly made for the application of fly ash [7]. Day by day, a new invention and research are going on for the bulk usage of fly ash. Now the use of fly ash in the bulk mode is applicable in the field of geotechnical engineering applications such that brick manufacturing, structural fills, filling of mines, production of embankments, construction of roads, haul roads etc. if fly ash used as above application then disposal area going to reduce and also cost of the projects should get low. An effort has been done in this research to assess the potential utilization of fly ash composite material made by mixing of fly ash, sand, and cement and lime. The improvement of the mechanical strength of fly ash with adding of cement or lime. There are several worked been done so far in the field of fly ash composite material made of cement and lime additives. Mishra et al. [8] had been proposed that F-type fly ash has several desirable properties that would make it for major voids filling. Mishra et al. [9] also suggested the fly ash composite material made by addition of lime and gypsum exhibited favorable characteristics to substitute for sand as back-filling material.

Mangaraj et al. [10] had done an experiment on sand replacement Levels (SRLs) of 0-30% with pond ash for the concrete having a w/c ratio of 0.60. They reported for the suitability of medium strength concrete, and it was observed that compressive strength also increased. Rafat Siddique [11] reported an extensive data on the effects of replacement of a fine aggregate with fly ash for the concrete with w/c ratio was 0.47 at 7 to 365 days. It was observed that the workability of concrete was less, but compressive strengths were improved. Dhir et al. [12] studied that significant improvement of compressive strength at all ages when used coarse aggregate contents fly ash as sand (fine aggregate) replacement material. Hwag et al. [13] reported that the strength of the mortars containing FA at sand replacement Levels (SRLs) of 25% and 45% was improved with w/c ratio of 0.03-0.50. Bakoshi et al. [14] reported that compressive and tensile strength of concrete with FA used as sand replacement material (SRM) was increased.

2.2 Fly Ash:

The by-product of the burning of pulverized coal in thermal power plants is generally defined as a Fly ash. Specifically, from the burning region of the boiler, the unburned residue e. i. fly ash carried away by the flue gases and then collected by either mechanical or electrostatic separators. The weightier unburned material drops to the lowermost of the furnace and is termed bottom ash; this material is not suitable for use as a cementitious material for concrete [15]. Fly ash is a pozzolanic material. Fly ash is a finely-distributed amorphous aluminosilicate with quantities of calcium varies. The elements present in the fly ash primarily consist of alumina. silica, alumina and iron [16]. Fly ash that contains small amount of lime, can reacts chemically with lime and cement form cementitious complex compounds at room temperature [17].

2.3 Classification of fly ash:

It is seen that various classifications have been proposed on the basis of different constituent material, characteristics, application, chemical properties or chemical properties. According to ASTM Specification (ASTM C 618, 1993), Fly ash is classified mainly as F-Type and C-Type fly ash (either pozzolanic or cementations materials).

Table-5: ASTM Specification for Fly Ash [18], [19]

Class	Description in ASTM C 618	Chemical Requirements
F	Fly ash generated from combustion of anthracite or bituminous coal that contains less than 20% lime (CaO). This class of fly ash has pozzolanic properties. Due to this pozzolanic property, cementing agents require in class f type fly ash, such as Portland cement, quick-lime or hydrated lime. At the presence of water, it produces cementations compounds.	$SiO_2 + Al_2O_3 + Fe_2O_3 \geq 70\%$
C	The combustion of lignite or sub-bituminous coal produces this C type fly ash that contains more than 20% lime (CaO). C type fly ash having pozzolanic properties also has some cementations properties. As class C type fly ash has self-cementing property, so it does not require an activator.	$SiO_2 + Al_2O_3 + Fe_2O_3 \geq 50\%$

2.4 Physical Properties of the Fly Ash:

Due to the presence of carbon from partial burning of coal, fly ash looks gray to black colour. The quantity of iron oxide is also affected in the appearance of fly ash. Overall, the colour of fly ash is grayish white [20].

Fly ash consists of very finely distributed spheroids of siliceous glass. The size of the particle is vary between 1 to 50µm in diameter. The most of the particles that are presence in the fly ash are smaller than Portland cement [21]. One of the significant physical parameter that necessary in development and implementation of geotechnical applications is specific gravity. The specific gravity is influenced by its chemical configuration of fly ash. Fly ash have low specific gravity as compared to soil due to the existence of extra number of cenospheres from that the removal of trapped air can't occur, or iron content in particular, the variation in the chemical composition, or both [22, 23]. The range of specific gravity of fly ash between 1.60 and 2.65 in India [22]. This variation in specific gravity of fly ash changes due to factors like the shape of the particle, a size of the particle, chemical composition, gradation, etc. The specific gravity increases with fineness and the finest fly ash have maximum specific gravity [24].

Table-6: Physical properties of fly ash [25]

Property	Fly ash
Specific gravity	2.16
% of Particle size investigation	
Sand (4.75 – 0.075 mm)	22.16
Silt (0.075 – 0.002 mm)	75.03
Clay (<0.002 mm)	2.80
Specific Surface Area (m^2/kg)	460
% of Liquid limit	30.65
% of Plastic limit	Non-plastic
% of Free swell index	Negligible

2.5 Chemical Properties of fly ash:

Fly ash is a complex inorganic-organic combination with unique, poly component, heterogeneous sand variable configuration. It is reported that about 188 minerals or mineral groups have been recognized in fly ash [26]. The fly ash is chemically influenced by various factors such as geological characteristics, the arrangement of the parent coal, burning method, corrosion regulator used, hopper location etc. [27]. Chemically coal is an organic material and mainly contains carbon, hydrogen, nitrogen, oxygen and sulphur. Main inorganic components associated with coal are clay minerals, silica, carbonates and sulphides, etc. The variation, decomposition and transformation by heating of organic and inorganic materials during the process of coal burning produce fly ash. The resulting fly ash contains compounds of silicon, aluminum, iron and calcium with lesser amount of compounds containing magnesium, titanium, sodium and barium as well as traces of other elements. Since the burning of coal is never broad, fly ash holds varying quantity of unburnt carbon called loss on ignition [27, 28]. Summation of individual components of silica, calcium oxide, iron oxide, alumina and magnesium oxides are more than 85% in fly ash [29]. Among that silica and alumina contains 45% to 80%. The components that major quantity in fly ash are silica (SiO2), alumina (Al_2O_3), iron oxide (Fe_2O_3) and calcium oxide (CaO) [20, 29]. It is found that the pozzolanic property of fly ash play significant role. The term pozzolana is defined as the siliceous and aluminious materilas that itself doesn't possesses any cementitious property but when it comes to contact with water, chemical reaction take place and form complex compounds having cementious properties[37]. Throne and watt stated that higher the influences of pozzolonic activities if the amount of SiO_2 + Al_2O_3 in the fly ash is high [38].

Table-7: Chemical properties and compositions of fly ash [29]

Components	%
SiO_2	51.78
Al_2O_3	37.75
Fe_2O_3	6.51
CaO	0.55
MgO	0.48
Na_2O	0.2
K_2O	1.62
TiO_2	2.75
LOI	2.6

2.6 Engineering Properties:

The engineering properties of fly ash based composite material is very important input for its successful usage. Fly ash as such exhibit little strength values but in presence of moisture as well as additives achieves strength. These external influences are typically determined by the compaction characteristics of the material.

2.6.1 Compaction characteristics-

It is observed that due to existence of cenospheres and plerospheres, fly ash has low dry density and high OMC compared to soil (Das and Yudhbir (2006)) [39]. The variation of moisture in the fly ash have less effect can be explained by air void present in fly ash [20]. Soils have 1 to 5% of air void where as fly ash content 5 to 15%. A report of proctor compaction curves for class F type fly ash was given by DiGioia et. al. (1986) [40]. They concluded the maximum dry density in the range of 11.9 to 18.7 KN/m^3 for the water content of 13 to 32%. It is observed that Indian fly ash have dry density of the range of 8.9 to 13.8% for the moisture content of 17.9 to 62.2% by sridharan et. al (2001) [20]. The huge variation of dry density and OMC in the fly ash is due to its specific gravity which depends on the carbon and iron contents [37].

2.6.2 Strength characteristics-

For the geotechnical utilization of fly ash, it is necessary to know about its strength characteristics. UCS of fly ash is a function of lime existing in free mode [41]. It was reported that UCS value of fly ash increases exponentially with the free lime by Yudhbir (1991). He also stated that the strength of fly ash reduce due to presence of carbon. Gray and Lin (1972) [42] observed for the British fly ash compacted for maximum dry density that the value of UCS at 7 days curing periods was 390 to 900 KPa which increased to 400 to 1200 KPa at 90 days of curing periods respectively. The self-hardening properties of fly ash are controlled by existence of free lime and calcium oxide or hydroxide [36]. An investigation was done by Ghosh and Subbarao (2006) that reported the UCS value of F type fly ash was 127 KPa at 7 days, 137 KPa at 28 days and 172 KPa at 90 days of curing periods. Mclaren and Digioia (1987) was reported for the partially saturation of class F fly ash, that shear strength mainly depends on the cohesion value. But in the case of dried or fully saturated condition, cohesion have negligible importance and at that time friction component was dominant [20]. It is observed that when density increases, its friction component increases. For the Indian fly ash, cohesion value changed from 16 to 93 KPa whereas the frictional angle varies from 33^0 to 43^0 obtained by drained test condition [36].

2.6.3 Ultrasonic Pulse Velocity-

Nondestructive testing is a useful technique which is applicable for the wide range of material analysis. This technique was developed by Jones (1949) in England and Cheesman and Leslie (1949) in Canada at the same time. It consists of passing ultrasonic waves through the body at one end and measuring the time taken to pass through at the other end. Ultrasonic pulse velocity was found to have increased over the time in the fly ash composite material with cement additive by Mishra et. al. (2003). UPV increased as curing periods increased of masonary composite material made by limestone power in the fly ash (Turgut, 2010) [43]. He also reported that UPV increased from 1150 to 1800 m/s for the composite of 10% fly ash at 7 days of curing periods. Dimter et. al. (2011) [44] stated that the increase of fly ash from 0 to 75%, UPV decreases. He reported that as the density of material increases, UPV also increases.

CHAPTER- 3

METHODOLOGY

3.1 General

The objective of the research was that to developed the fly ash composite with the additives like lime and cement, and evaluates their strength parameters. This chapter includes the materials used for the analysis and method adopted to achieve the objective of our experiment. Main ingredients used were fly ash, sand, cement and lime. Sample preparation, testing and analysis procedures used for development of composite materials and characterization of fly ash materials are described below.

3.2 Materials and Methods:

The details of materials used in this investigation are as mentioned in following sections

3.2.1 Fly ash:

Rourkela Steel Plant (RSP) [30] has consumed 2230 ton of coal in a year and generated 600 ton fly ash. The fly ash was taken from RSP, SAIL. The application of fly ash in the current investigation was collected from electrostatic precipitators in hoppers, finer particles that come out with flue gasses are collected as fly ash. To collect the dry fly ash, a 50 kg capacity of each poly-coated cotton bag was used. The mouth of each bag was sealed instantly after collection of fly ash to avoid atmospheric impacts. The bags were transported from plant to workshop with precaution. Bags kept in a safe place and also controlled surroundings.

Fig. 2; Fly ash Sample used for the experiment

3.2.2 Lime:

The strength of fly ash was enhanced with the use of Lime [31]. The lime used in the current experiment, was produced from 'LobaChemie' India. It is pure Calcium Hydroxide. The different percentage of lime used were 3, 5 and 8. It compositions are

Table 8

Composition of Lime

$Ca(OH)_2$	M.W. 74.08
Assay (acidimetric)	Min 95.1%
Maximum limit of impurities	
Iron (Fe)	0.1%
Sulphate (SO_4)	0.4%
Chloride (Cl)	0.04%
Heavy metals (as Pb)	0.005%
Substances not precipitated by ammonium oxalate (as Sulphate)	2.50%

Fig. 3; Collection of lime

3.2.3 Cement:

Cement is a substance that hardens and binds other materials together. The most common type of Portland cement is called ordinary Portland cement (OPC) which is gray in color [32]. This process of manufacturing of the Portland cement is known as Calcination. The Portland cement that was used in this experiment is a product of 'Konark' Brand cement (43 GRADE) of OCL, Rajgangpur, Odisha, India [33]. The percentage of cement used was 3, 5 and 8.

Fig. 4; Collection of cement

3.2.4 Sand:

Colour of sand is light yellowish brown. Sand is a loose granular substance which produces by resulting from the erosion of siliceous and other rocks and making a major constituent of beaches, riverbeds, and deserts. The composition of sand depends on the erosion of rocks which is made by what type of element. But the most common constituent of sand in the earth is silica (silicon dioxide, or $SiO2$) [34]. Sand that used in the current experiment is taken from 'KOYAL' River, Rourkela, Odisha. For this experiment, the particle size of sand aggregate was below 4.0 mm. The percentages of sand were 12, 20 to 27.

3.5 Sample description:

Different % of fly ash, sand, lime and cement were added for making the different composite material. The curing periods were also changed to 0, 7, 14, 28, 56 and 90 days. All fly ash composite materials were placed inside the humidity chamber. Temperature of the humidity chamber maintained at room temp. (i.e. 25^0C) and humidity was achieved up to 90%. The different composite material in various proportions is given in the following table.

Table-9: Various proportions of fly ash, sand, cement and lime

Sl. No.	Composition ID	Fly ash (%)	Sand (%)	Cement (%)	Lime (%)
1	C3%	85	12	3	-
2	C5%	75	20	5	-
3	C8%	65	27	8	-
4	L3%	85	12	-	3
5	L5%	75	20	-	5
6	L8%	65	27	-	8

3.6 Experimental Size:

The investigation was carried out by doing many laboratory tests like Proctor Hammer Test, Unconfined Compressive Strength (UCS) Test, Brazilian Tensile strength (BTS) Test, Direct Shear Test (DST) and Ultrasonic Velocity Test (UVT). Except that for compaction test, the reported results in next chapter represent the average values of 2 to 3 specimens for each type of test. The test results that were not within the range from 0% to 12% of each other were discarded and fresh specimens were prepared and tested.

Table-10: Total sample size

BTS	UCS	DST	UVT
72	72	216	72
Total no of samples = 432			

Before going to sample preparation, we had to find out the optimum moisture content by the various proportion of the composite material. At optimum moisture content, sample having maximum dry density, lead to achieving the maximum strength of the composite. Compaction was obtained by the standard Proctor procedure. Proctor hammer test is generally used to predict the amount of water which will be mixed with the mixture so that dry density will high. The amount of water added to different mixture according to the result of Proctor Compaction test.

3.7 Modified Proctor compaction test:

These test methods cover laboratory compaction methods as per IS: 2720-Part 8 (1983). This test is used to determine the relationship among moulding water content and dry unit weight of soils (compaction curve). Compaction is done in a 101.6 mm diameter mould. A 24.5 N hammer dropped from the height of 305 mm. The equipment that are used for the standard proctor compaction test is given below-

3.7.1 Equipment:

- Number of the sieve.
- Mould of compaction.
- Standard proctor hammer.
- Large flat pan.

3.7.2 Procedure:

- ❖ 2 Kg of air dry fly ash, sand and cement/lime is taken and mixed in a container for proctor hammer compaction test is conducted.
- ❖ Sufficient % of water was added.
- ❖ W_1 (wt. of mould and base plate) was determined after that extension was attached to the top of the mould.
- ❖ Poured the fly ash mixture into the mould in three equally distributed layers. Each layer should be compacted uniformly by the modified proctor hammer 25 times. Than the next layer of fly ash mixture was poured into the mould.

- Extension was removed and excess soil was trimmed from the mould.
- The weight of mixture mould, W_2 was determined.
- The moisture can was taken and its mass, W_3 was determined.
- Mass of cane and moisture soil, W_4 was determined.
- The moisture was placed in an oven with the moist mixture in the pan to dry a constant weight.
- Fresh material was taken and above process was repeated with different composition and water.

Fig. 5; Mixture of Fly ash, Sand and Cement

Fig. 6; Proctor compaction, mould and hammer

3.8 Sample for Brazilian Tensile strength test:

The direct tensile strength of rock or soil material is difficult to determination. So, there is an indirect technique of its determination is used called as Brazilian tensile strength. In the test, specimen failure is under tension, however, the pattern of loading is compressive in nature. The determination of this tensile strength is as per the ASTM D3967. A circular disk type of sample is prepared having thickness to diameter ratio (*t/D*) between 0.5 and 0.75. A cylinder mould of

58 mm diameter and 35 mm length was prepared for the tensile test experiment. The final prepared specimen had the thickness to diameter ratio of 0.5 by cutting the mould which prepared. The circular sample prepared having thickness around 29 to 31 mm and diameter 58 mm. The sample of Tensile Strength test is shown in figure 7.

Fig. 7; Sample for Tensile Strength test

For each composition of fly ash, two samples were prepared and an average of their data was taken as final result. The total numbers of sample were 72.

3.9 Sample preparation for unconfined compressive strength (UCS) Test:

A cylindrical sample of soil is trimmed such that the ends are reasonably smooth. Samples were prepared as per IS: 2720-Part 10 (1991). A cylinder mould of 125-130 mm length and 58 mm diameter sample was prepared for the unconfined compressive strength (UCS) test. The prepared sample had a length to diameter ratio of 2 to 2.5. The specimen for unconfined compressive strength (UCS) test is shown in figure 8.

Fig. 8; Sample for Unconfined Compressive Strength test

Two samples are prepared for each test for getting more appropriate result. The total numbers of sample were 72.

3.10 Sample preparation for Direct Shear Test:

The fly ash, sand cement or lime with sufficient water to produce the desired water content is mixed for preparing the sample. the dimension of the sample is 60*60*25 mm (length*width*height). The specimen for Direct Shear test is shown in figure 9.

Fig. 9; Sample for Direct Shear Test

Sample of each composition is tested under three normal load i.e. 0.5, 1.0, 1.5 KN. Two samples are prepared for each test for getting the more Precise result. The total numbers of sample were 216.

3.11 Sample preparation for Ultrasonic Pulse velocity test:

A cylinder mould of the unconfined compressive strength (UCS) test sample was used for the preparation of the sample for this test. Cylindrical mould had 58 mm diameter and 130 mm. The final prepared specimen had a length to diameter ratio of 2 to 2.5. The typical specimen for Ultrasonic Pulse velocity test is shown in figure 10.

Fig. 10; Sample for Ultrasonic Pulse velocity test

The relationship between different parameters like density, pulse velocity, elastic constants and modulus values are given by the following equations.

$$E= [P*V_S^2 (3V_p^2 – 4V_s^2)]/ (V_p^2 - V_s^2)$$

$$G= p V_s^2$$

$$\mu= (V_p^2 - 2 V_s^2)/ [2(V_p^2 - V_s^2)]$$

$$K= p (3V_p^2 - 4V_s^2)/3$$

Where,

V_p= compression wave velocity, m/s

V_s= shear wave velocity, m/s

μ = Poisson's ratio

P = density, Kg/m^3

K = Bulk modulus, Pa

E = Modulus of elasticity or Young's modulus, Pa

G = shear modulus, Pa

For each composition of fly ash, two samples were prepared and average of their data is taken as final result. Total 72 number of sample were prepared.

CHAPTER 4

EXPERIMENTATION

According to established methods, the geotechnical properties of the all developed composite materials were determined. All the results of the present research have been stated in different sections as mentioned below.

4.1 Brazilian Tensile Strength Test:

It is difficult to determine the direct tensile strength of soil or rock material. Therefore, generally an indirect way of the method is used in practice for the determination of tensile strength that is called Brazilian Tensile Strength test. The pattern of loading is compressive and through that samples of Brazilian test fracture under the tension strength. The experiment had done for tensile strength test according to standard ASTM D3967.

4.1.1 Procedure:-

- Determined the dimension of the fly ash based sample (i.e., length and diameter).
- The sample was put between lower and upper platens of the machine.
- The sample was set at the center.
- Dial gauge arrow was set to at zero position.
- A constant rate of loading was applied to sample so that failure occur in between 1 to 10 minutes of loading
- The Dial Gauge reading at fracture was recorded.
- This process was repeated one more time for the specific composition of the fly ash composite material. For example, composition ID C3% (i.e., fly ash 85%, sand 12% and cement 3%) was done two times testing.
- These steps were repeated for the other fly ash composition.

Fig. 11; Sample testing for tensile strength test

Fig. 12; Failure profile of Sample testing for tensile strength

4.1.2 Calculation:-

Tensile stress,

$$\sigma_t = 2P/\pi DT$$

Where,

σ_t = Tensile strength of composite material

P = Failure load

D = Specimen diameter

T = Specimen thickness

4.2 UNCONFINED COMPRESSION TEST (UCS):

The UCS is defined as the material offering a resistance to any external loading. The UCS is determined by applying an axial load to a cylindrical fly ash composite material with no confining pressure. The stress at which failure in the fly ash-based specimen occurs is referred to as the Unconfined Compressive Strength. The UCS value for the coarser fly ash- based sample is lower than the fly ash-based sample [35]. The present of free lime in the form of calcium hydroxide, calcium oxide, regulator self-hardening characteristics of fly ash composite [36].

4.2.1Equipment:-

1. Servo controlled loading unit-
   - Capacity 1000 KN
   - Horizontal clearance 450 mm
   - Vertical clearance 650 mm
   - Stress rate 1 KN/sec to 10 KN/sec
   - Strain rate 0.001 m/sec to 2 mm/sec

2. Extensometer-
   - Axial extensometer,
   - Diametrical extensometer.

3. Data acquisition and controlling system.

4.2.2 Procedure:-

- The sample was properly trimmed so that the surface is properly aligned with the platen.
- Determined the dimension of the fly ash composite material sample (i.e., length and diameter).
- The sample was placed in between lower and upper platens loading device. It was the middle of the lower platen.
- The adjustment of loading device was carefully so that loading platen was just touched the sample.
- An extensometer was used for the measurement of deformation along longitudinally and diametrically.
- We were given the rate of loading 0.002 m/s.
- Loading was applied up to the post-failure of the specimen.
- All the data like peak load and deformation were saved in the computer.
- Same steps were repeated for all composite material of fly ash.

Fig. 13; Sample testing for UCS

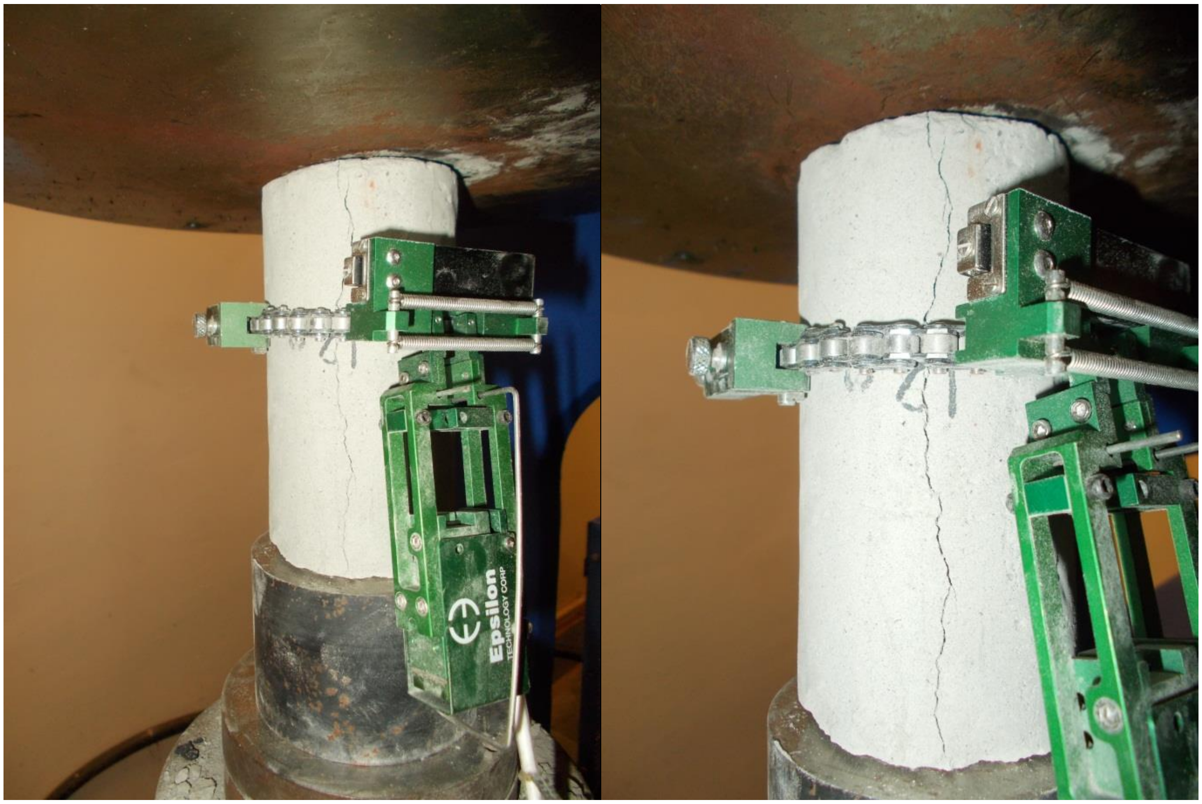

Fig. 14; Failure profile of Sample testing for UCS

4.2.3 Calculation:-

The equation for UCS is

$$\sigma_c = P/A$$

Where,

σ_c = unconfined compressive strength,

P = load at failure,

A = cross sectional area of the sample.

The equation for Young's Modulus is-

$$E = \sigma_c/\varepsilon$$

Where,

E = Modulus of elasticity (Young's Modulus),

σ_c= unconfined compressive stress,

ε = Axial strain.

The results of unconfined compressive strength tests i.e. value of Young's modulus and Poisson ratio of different composition IDs were given below:

Table-11: The value of Young's Modulus (E, MN/ m^2) during different curing periods

composition/days	0	7	14	28	56	90
3% Cement	2.5074	5.647643	8.72406	11.30249	14.06532	17.20355
5% Cement	8.670404	15.80178	26.2737	41.26951	51.50072	66.777
8% Cement	16.93645	37.23173	52.80579	59.44014	99.19201	139.0764
3% Lime	2.182548	3.957285	6.743647	9.421746	14.78337	15.22535
5% Lime	7.77879	18.98276	27.59126	35.04951	43.4827	55.3635
8% Lime	16.62265	29.03565	38.10265	50.32958	82.33359	103.251

TABLE-12: Poisson ratio at different curing periods of static test

composition/days	0	7	14	28	56	90
3% Cement	0.486205	0.432848	0.401253	0.320197	0.302732	0.28921
5% Cement	0.43424	0.398467	0.346281	0.328561	0.295172	0.27333
8% Cement	0.390699	0.332754	0.26818	0.244174	0.228995	0.201276
3% Lime	0.467133	0.410799	0.390377	0.327091	0.300391	0.296158
5% Lime	0.419942	0.368762	0.350422	0.322465	0.305753	0.289321
8% Lime	0.39588	0.342516	0.270631	0.263427	0.2421	0.236312

4.3 Direct Shear Test:

Failures of the material under the direct shear stress occur along the shear plane. Generally shear stresses are distributed nonuniformly within the sample. The stress value at the failure of the specimen is termed as shear stress. This test had been done according to ASTM D3080/D3080M-11.

4.3.1 Apparatus:-

Loading Devices, Shear Device, Shearing Box, , Normal Force Measurement Device, Shear Force Measurement Device, Deformation Indicator.

4.3.2 Procedure:-

- The sample was properly trimmed so that the surface is properly aligned with the platen.

- Determined the dimension of the fly ash composite material sample (i.e., length, width and height).
- The sample was placed inside the shear box assembly.
- Two vertical pins were adjusted to hold two halves of the shear box together
- Assemble shear box system was placed inside the direct shear device.
- For Applied preferred normal load (N) on the shear box assembly, hanging dead loads to vertical weight yoke.
- Deformation indicator was touched to shear box assembly.
- After that, applied shear load on the shear box assembly till the failure.
- Dial gauge’s reading was recorded.
- Same steps were repeated for all composite material of fly ash.

Fig. 15; Sample testing for Direct Shear Strength test

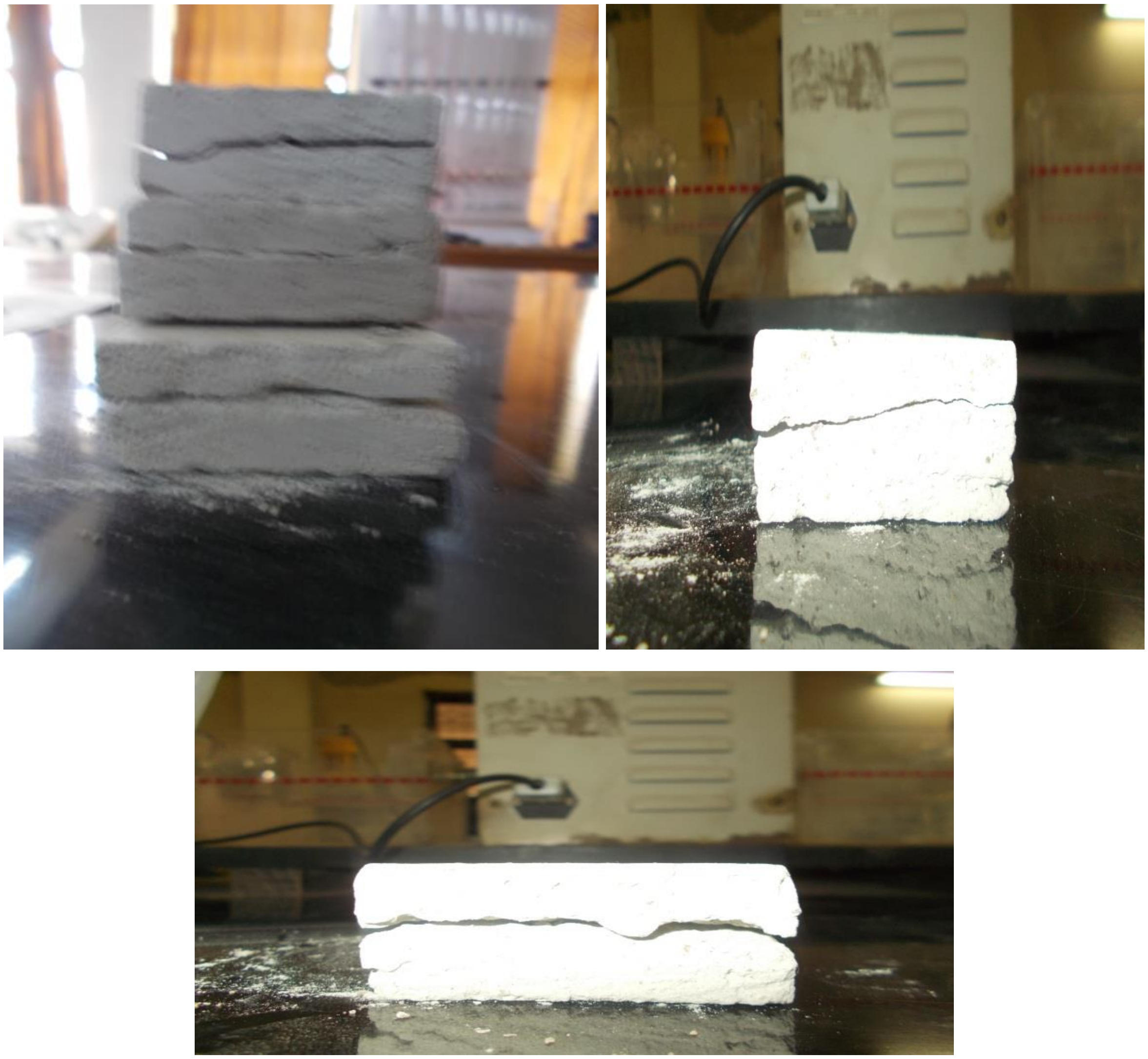

Fig.16; Failure profile of Sample testing for Direct Shear Strength test

4.3.3 Calculation:-

The equation for direct shear test is –

$$\tau = S / (W*H)$$

$$\tau = \sigma_n * \tan(\Phi) + C$$

Where,

τ = direct shear stress,

S = shear load applied on the shear box assembly,

W = width of sample,

H = height of sample.

σ_n = Normal stress

Φ = Internal friction angle

C = Cohesion

DST was done at 3 different normal loads at 0.5, 1.0 and 1.5 Kgf. The results of DTS tests i.e. direct shear strength, cohesion and Internal friction angle of different composition IDs are given below:

Table-13: Direct shear stress (MN/m^2) at 1.5 Kgf Normal loads and different curing periods

Composition/Days	0	7	14	28	56	90
3% Cement	0.021915	0.026611	0.054787	0.062613	0.07044	0.081233
5% Cement	0.065744	0.090789	0.109573	0.125227	0.142445	0.14859
8% Cement	0.111139	0.186275	0.200363	0.273933	0.313067	0.35948
3% Lime	0.017219	0.018784	0.040699	0.048525	0.054787	0.071546
5% Lime	0.048525	0.065744	0.081397	0.089224	0.104877	0.147933
8% Lime	0.098616	0.118965	0.162795	0.25828	0.273933	0.316777

4.4 Ultrasonic Pulse velocity test:

This test is a non-destructive testing method and it is used to reflect the dynamic properties of materials. This technique is effective for wave velocity measurement in both isotropic and anisotropic materials. In anisotropic materials, velocities measured can be affected by many reasons such as the structure of material, direction, dampness, dimension of transducer and softness existence.

Ultrasonic Velocity Measurement System (made: GCTS, USA) was used to measure all pulse velocity (Figure 18). This machine has 10 MHz bandwidth receiver pulse with raise time less than 5 nano-seconds, 20MHz acquisition rate with 12-bit resolution digitizing board, 200 KHz shears mode and transducer platens with 200 KHz compression mode. Pulse and wave velocity generated from GCTS machine were used to determine the elastic constants.

The experiment was done according to ASTM D 2845-05. The Ultrasonic Pulse Velocity test is a measurement of the transit period of a longitudinal vibration wave through a sample along with known path length. Transmitting and receiving transducers is placed opposite end surface of the specimen. The representative demonstration of UPV test device is given below in Figure 17.

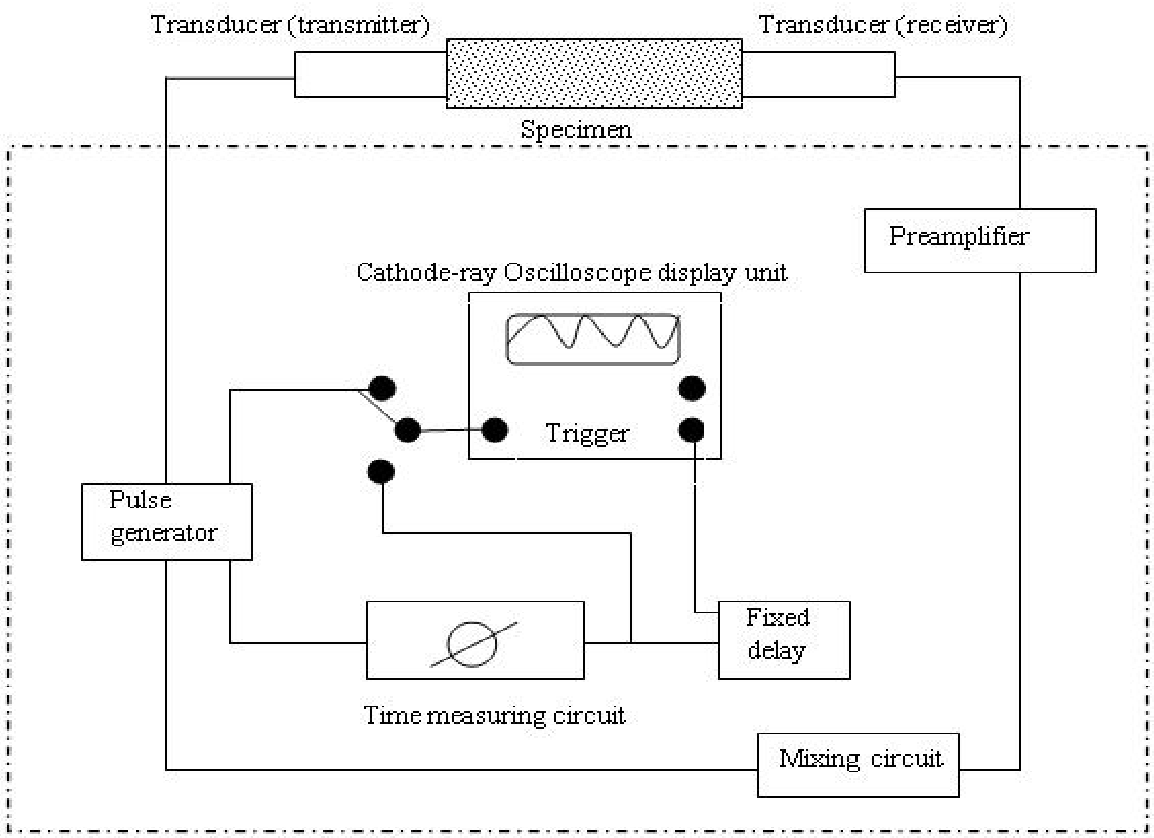

Fig. 17; Schematic representation of UPV test

Electrical impulses are created by pulse generator of a specified frequency. These electrical pulses are changed into elastic waves and transmit by transmitter inside the specimen. The receiver transducer receives the mechanical energy of the propagating pulse through specimen. Receiver transducer is placed the opposite direction of sample. It converted to electrical energy from the mechanical energy of the same frequency. This pulse travel time is recorded by an oscilloscope.

Fig. 18; An experimental setup for UPV measurement system

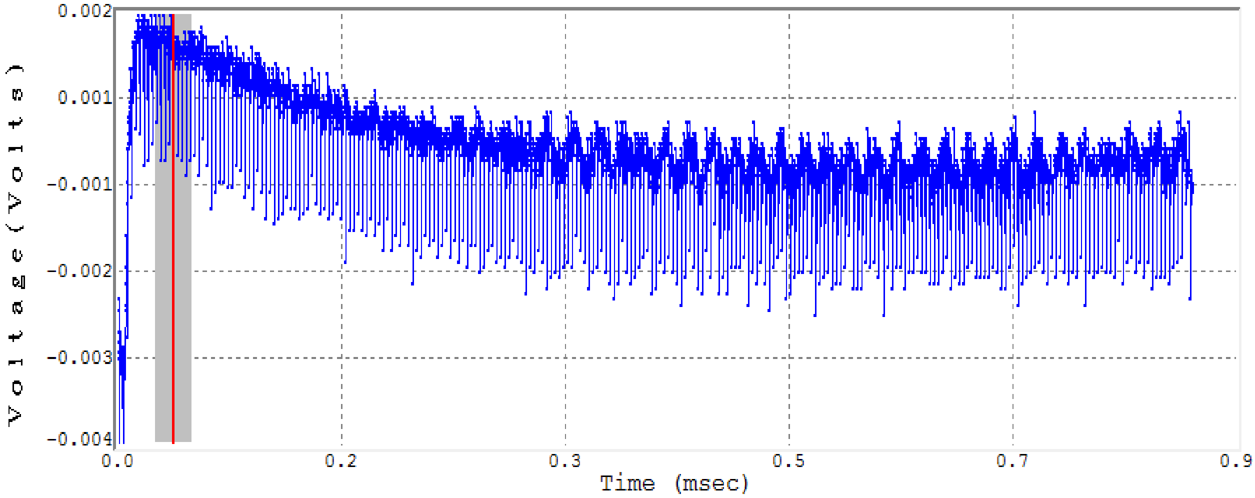

Fig. 19; A typical P wave velocity signal plot of fly ash composite

The Poisson's ratio is an important parameter of a material under loading. The Poisson's ratio values obtained from ultrasonic pulse velocity test are given below -

Table-14: Poisson's Ratio Values of Developed Composite Materials

composition/days	0	7	14	28	56	90
3% Cement	0.44	0.4	0.36	0.35	0.33	0.3
5% Cement	0.41	0.37	0.32	0.33	0.29	0.27
8% Cement	0.33	0.31	0.3	0.29	0.27	0.24
3% Lime	0.41	0.38	0.35	0.36	0.32	0.33
5% Lime	0.39	0.36	0.33	0.34	0.3	0.28
8% Lime	0.35	0.33	0.3	0.31	0.27	0.26

CHAPTER 5
RESULTS AND DISCUSSION

The investigation focused on evaluation and effect of various parameters on the strength of fly ash composite materials. The appropriateness of fly ash composite material depends on its several geotechnical properties. The following section deals with the impact of curing period, Lime and cement content on the fly ash composite materials.

5.1 COMPACTION TEST:

There exists a direct relation between material density and its strength value. The more the density, the more the mass and hence the more the strength or resistance to external loading. Maximum density is achieved at optimum moisture content. In this investigation the optimum moisture content at maximum density were determined for each composite and then the data were used to prepare the sample for UCS, BTS, etc. The flowing discusses the OMC-MDD data for each type of fly ash composite.

Composition of 75% FA, 20% sand and 3% cement-

From the graph (fig. 20), it was observed that dry unit weight of fly ash mixture increases with increase in % of moisture but up to certain level after that dry unit weight start decreasing with increase in water. Dry unit wt. was maximum at 24.5 % of moisture.

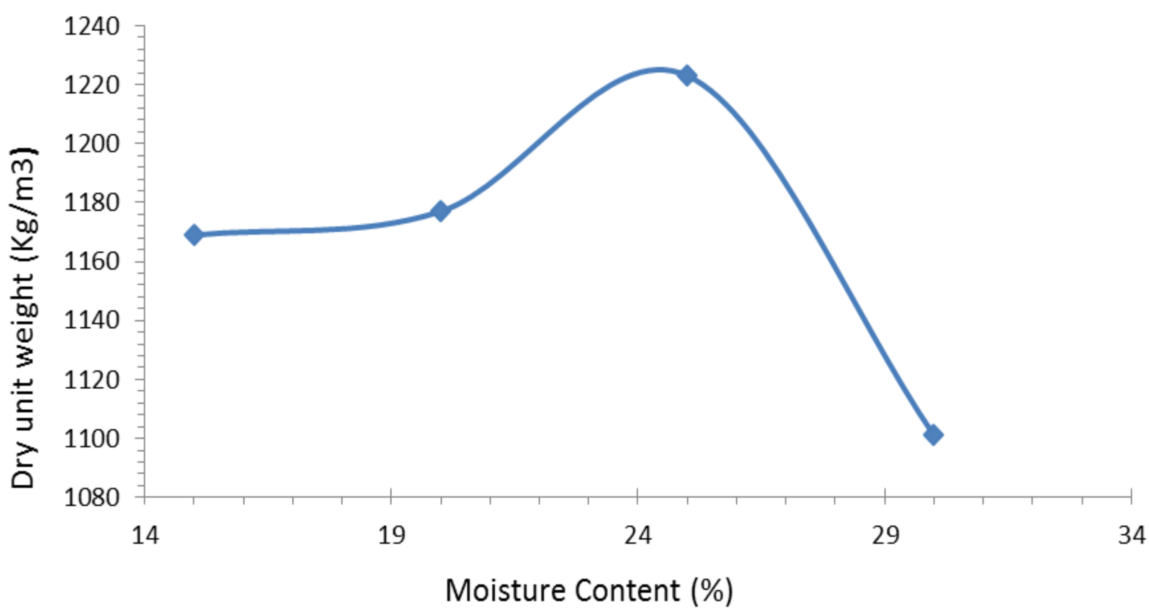

Fig. 20; Dry unit wt. vs. MC of 3% cement

Composition of 75% FA, 20% sand and 5% cement-

It was observed that dry unit weight of fly ash mixture increases with increase in % of moisture but up to certain level after that dry unit weight start decreasing with increase in water. Dry unit wt. was maximum at 23.5 % of moisture (fig. 21).

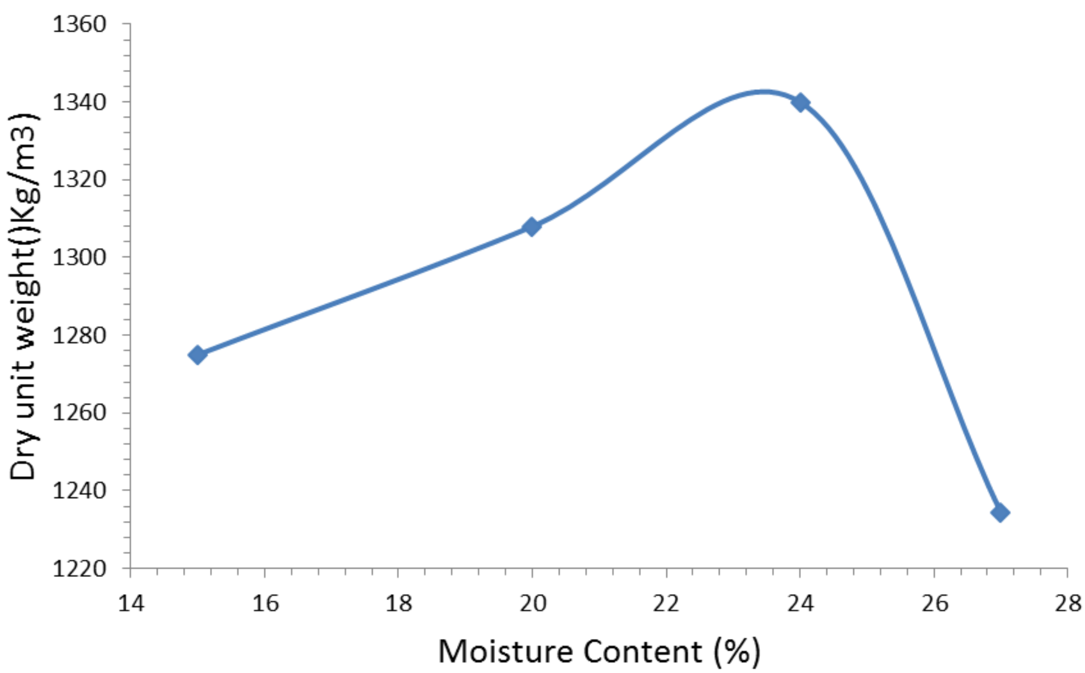

Fig. 21; Dry unit wt. vs. MC of 5% cement

Composition of 75% FA, 20% sand and 8% cement-

it was observed that dry unit weight of fly ash mixture increases with increase in % of moisture but up to certain level after that dry unit weight start decreasing with increase in water (fig. 22). Dry unit wt. was the maximum at 21 % of moisture. As the amount of fly ash decreases in mixture, % of moisture content decreases.

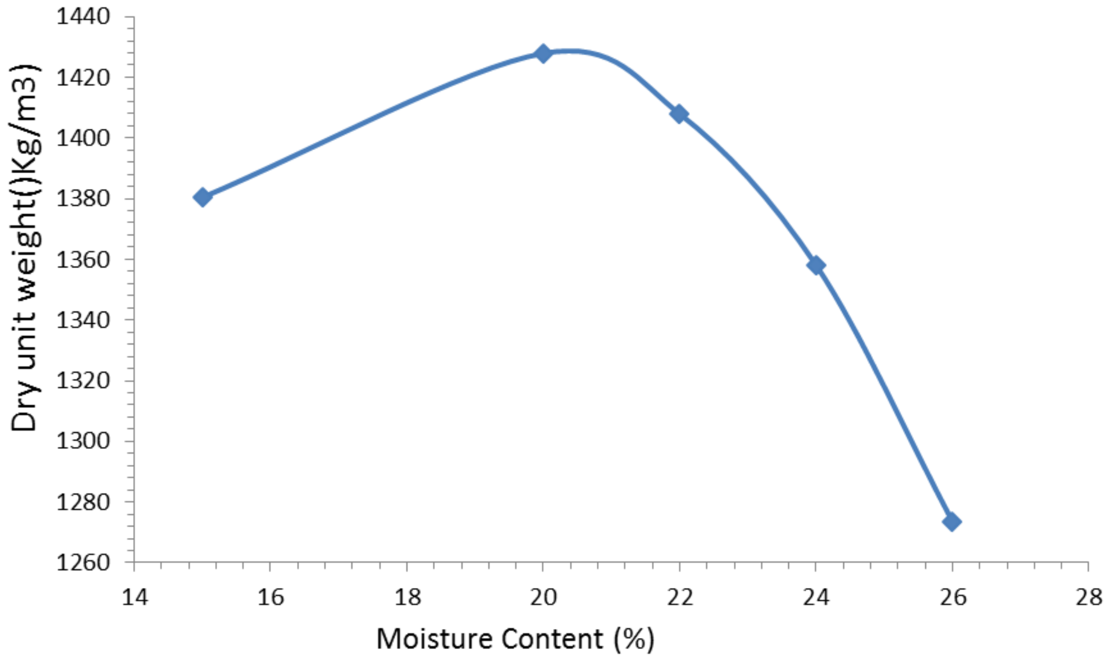

Fig. 22; Dry unit wt. vs. MC of 8% cement

Composition of 75% FA, 20% sand and 3% lime-

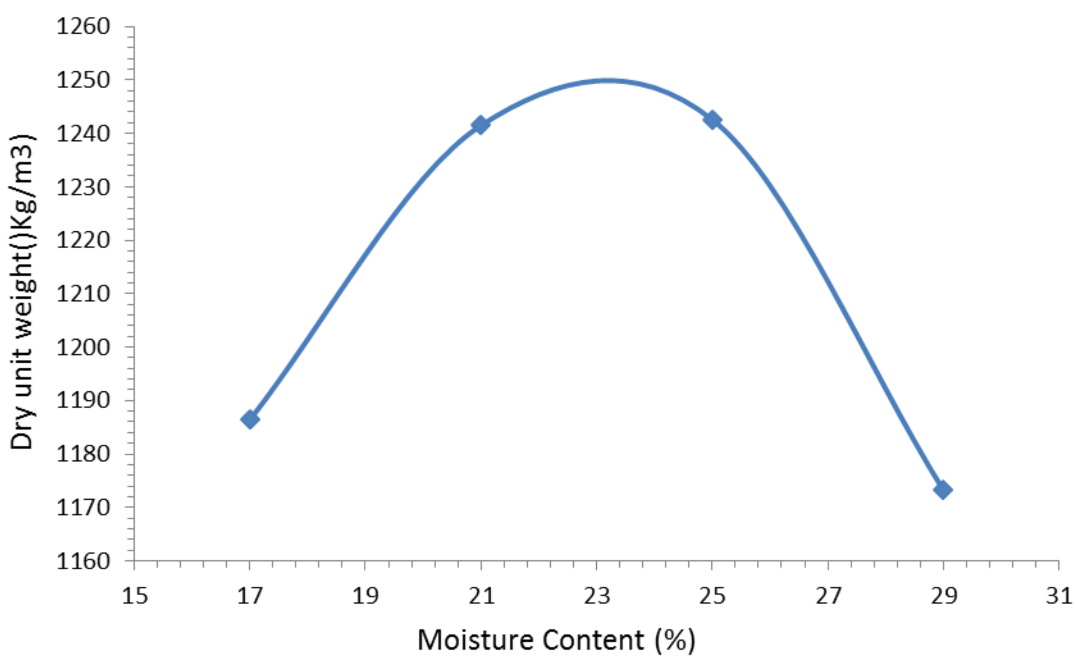

Fig. 23; Dry unit wt. vs. MC of 3% lime

For the lime additive, trend of graph (fig. 23) was similar to the cement additive but magnitude of moisture content was low. It was observed that dry unit weight of fly ash mixture increases with increase in % of moisture but up to certain level after that dry unit weight start decreasing with increase in water. Dry unit wt. was the maximum at 24 % of moisture.

Composition of 75% FA, 20% sand and 5% lime-

It was observed that dry unit weight of fly ash mixture increases with increase in % of moisture but up to certain level after that dry unit weight start decreasing with increase in water. Dry unit wt. was the maximum at 22.5 % of moisture (fig. 24).

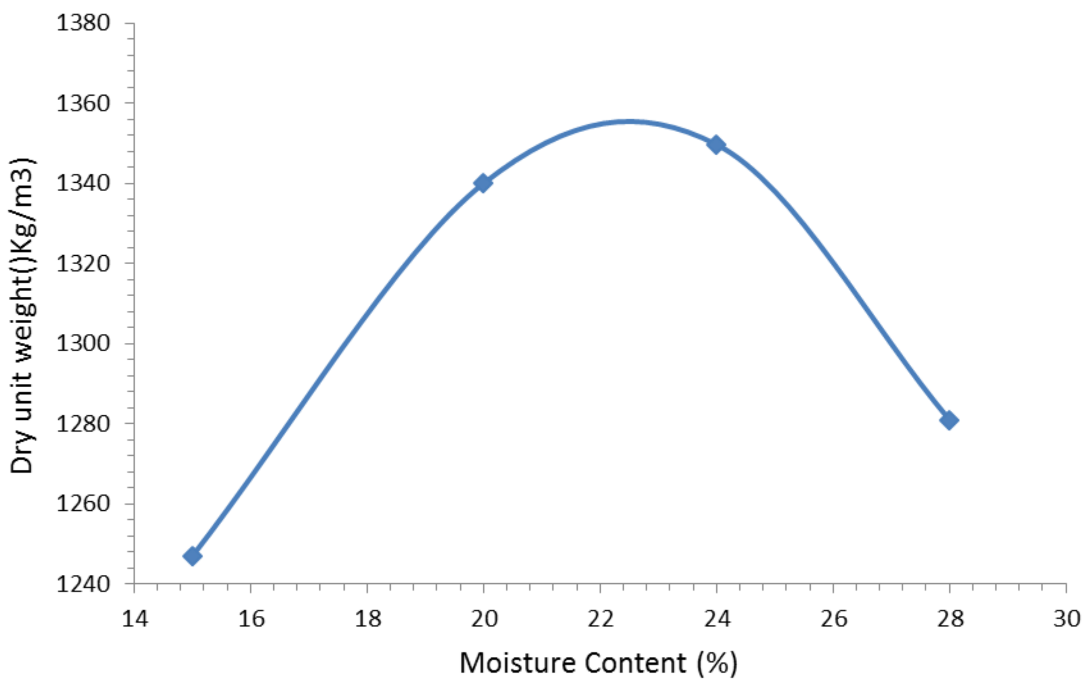

Fig. 24; Dry unit wt. vs. MC of 5% lime

Composition of 75% FA, 20% sand and 8% lime-

It was observed that dry unit weight of fly ash mixture increases with increase in % of moisture but up to certain level after that dry unit weight start decreasing with increase in water. Dry unit wt. was the maximum at 20 % of moisture (fig. 25). As the amount of fly ash decreases in mixture, % of moisture content decreases.

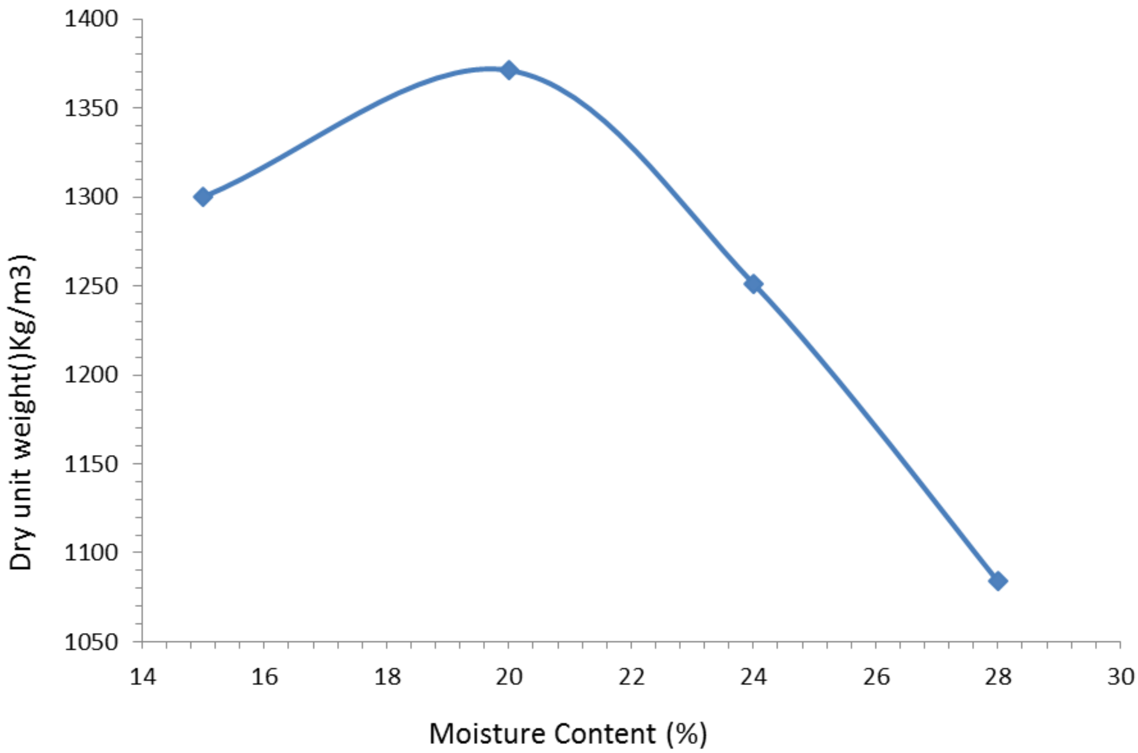

Fig. 25; Dry unit wt. vs. MC content of 8% lime

5.2 Brazilian Tensile Strength (BTS):

After all experimental results, it is observed that BTS value increases as curing period increases and also with an increase in % of cement and lime. The rise of the strength in case of cement addition is more as compare to that in case of lime addition. The value BTS in the range of 35.635 to 197.61 KPa of the 8% cement composition of fly ash, which is more than the range of 29.16 to 171.7 KPa of the 8% lime fly ash composite materials. The rate of increasing 87.5% at 8% is the maximum between 7 to 14 days of the curing period as compare to other % of cement. As curing period increases; the rate of increasing is slow for 3% of cement and going to parallel with X-axis. The trend obtained with lime addition is same but in the lesser magnitude. Rate of increasing is maximum 85.71% at 8% lime between 7 to 14 days of curing periods.

Relationship between BTS and curing period, cement and lime can be seen in the graph below (fig. 26, 27, 28, and 29).

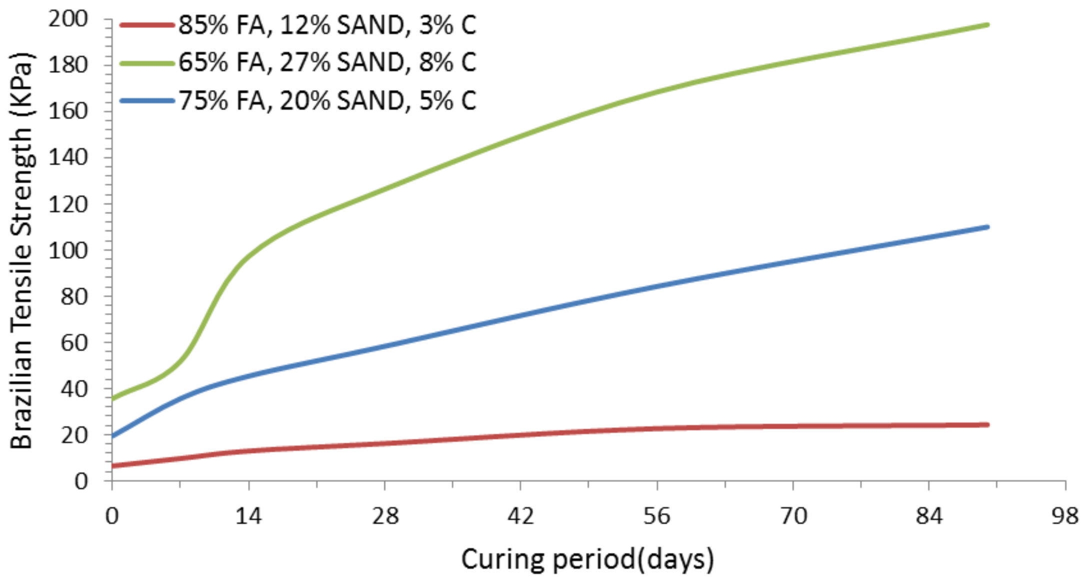

Fig. 26; Brazilian Tensile strength (KPa) vs. curing periods (days)
For cement composition

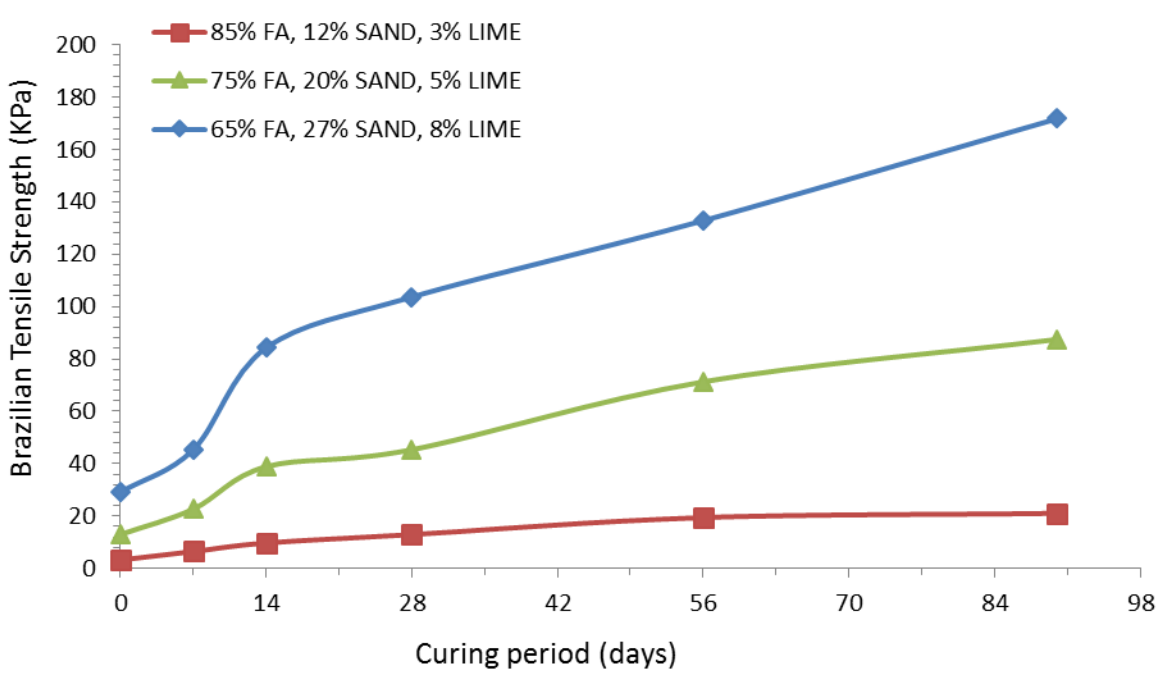

Fig. 27; Brazilian Tensile strength (KPa) vs. curing periods (days)
For lime composition

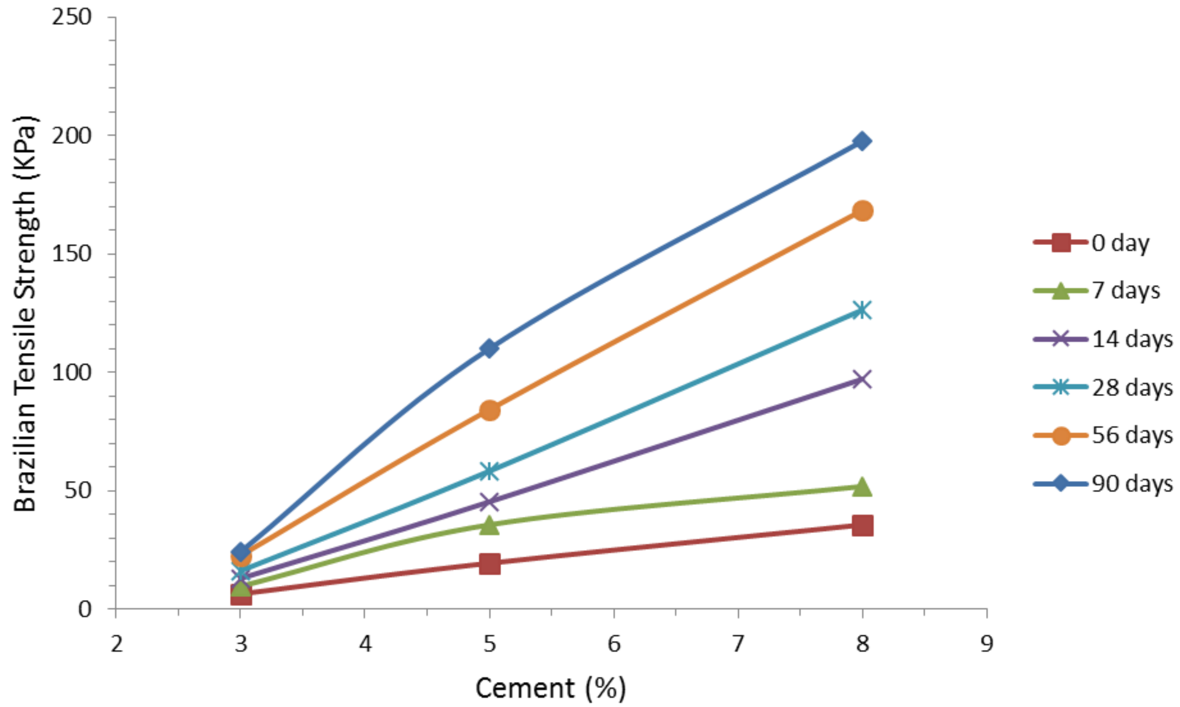

Fig. 28; Brazilian Tensile strength (KPa) vs. Cement (%)

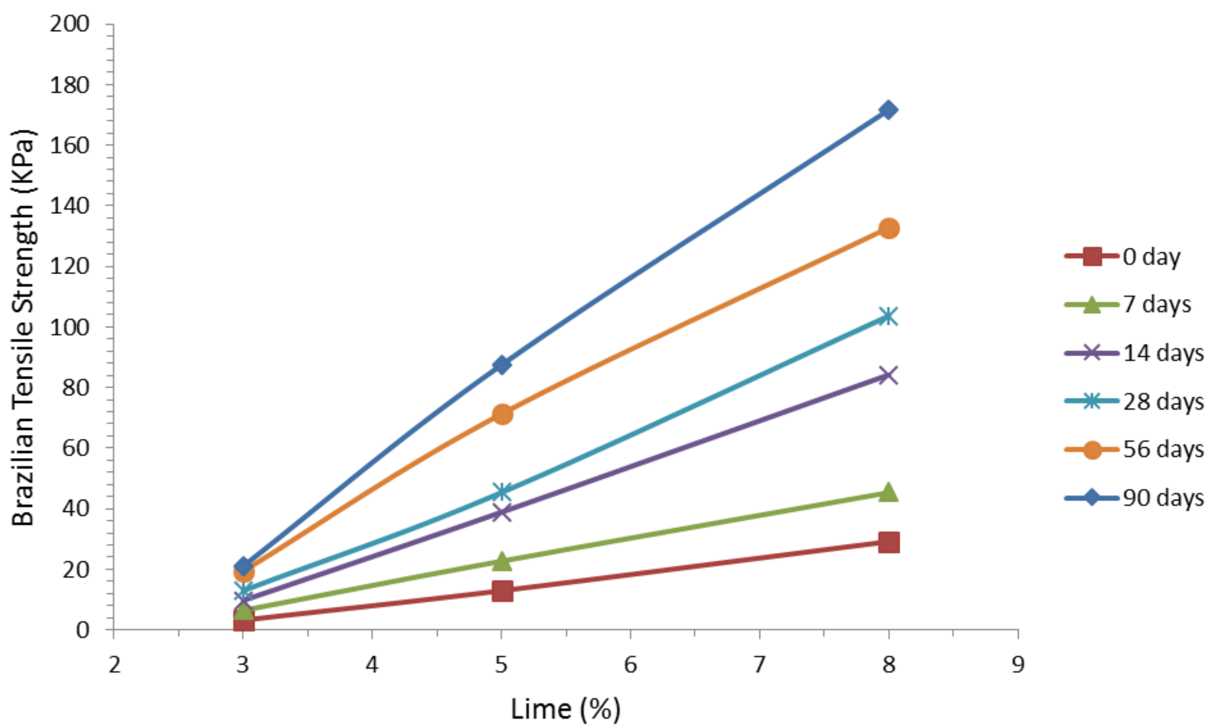

Fig. 29; Brazilian Tensile strength (KPa) vs. Lime (%)

5.3 Unconfined compressive strength (UCS):

It is observed that UCS value increases as curing period increases and also with the increase in % of cement and lime. The UCS values of all freshly prepared fly ash composite materials i.e. at 0 day, are between 0.114 and 0.468 MPa for cement composite and from 0.076 to 0.382 MPa for lime of 3%, 5%, 8%. At 3% of cement, the rates of increase slow down and almost asymptotic to X-axis as curing period increases. These values of UCS are very low due to weak development of bonds. The rate of increase of 44.44% at 8% cement s the maximum between 0 to 7 days as compared to other percentage of cement. At 5% of cement, the UCS valve is achieved to 1.63 MPa whereas at 8% of cement is 2.385 MPa for 90 days curing period. It is observed that, the trend obtained with lime addition is same as in case of cement addition but with reduced magnitude. At 8% of lime, maximum UCS value obtained is 2.12 MPa at 90 days curing period and shows a reduced trend through rate. A variation of UCS with curing period, cement and lime is shown below in the graph (fig. 30, 31, 32, and 34).

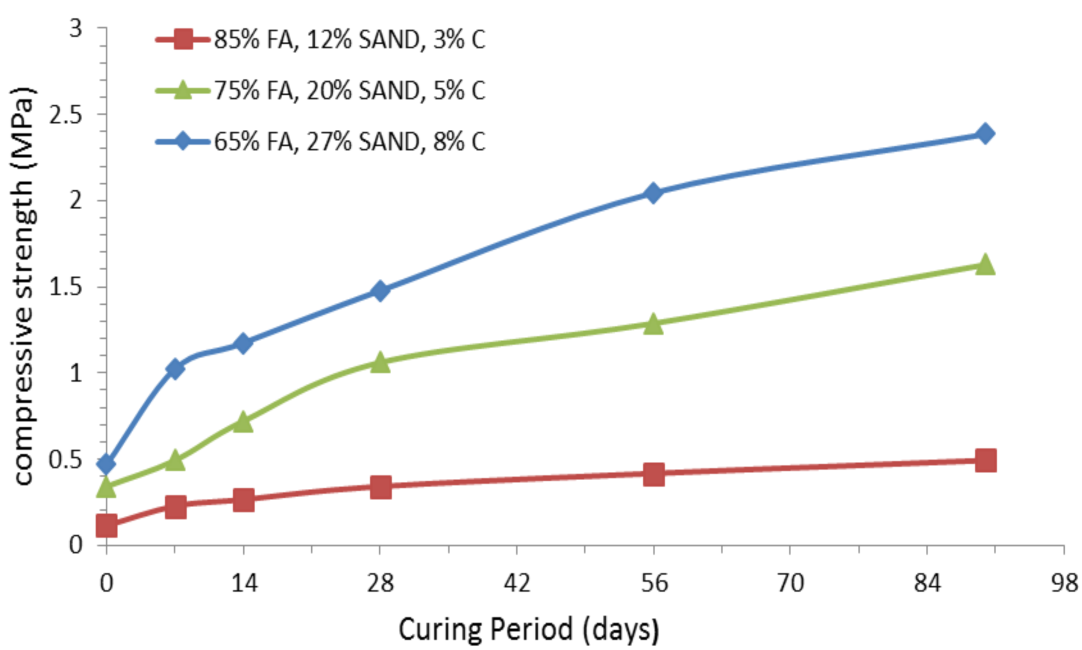

Fig. 30; Unconfined compressive strength (MPa) vs. curing periods (days)
For cement composition

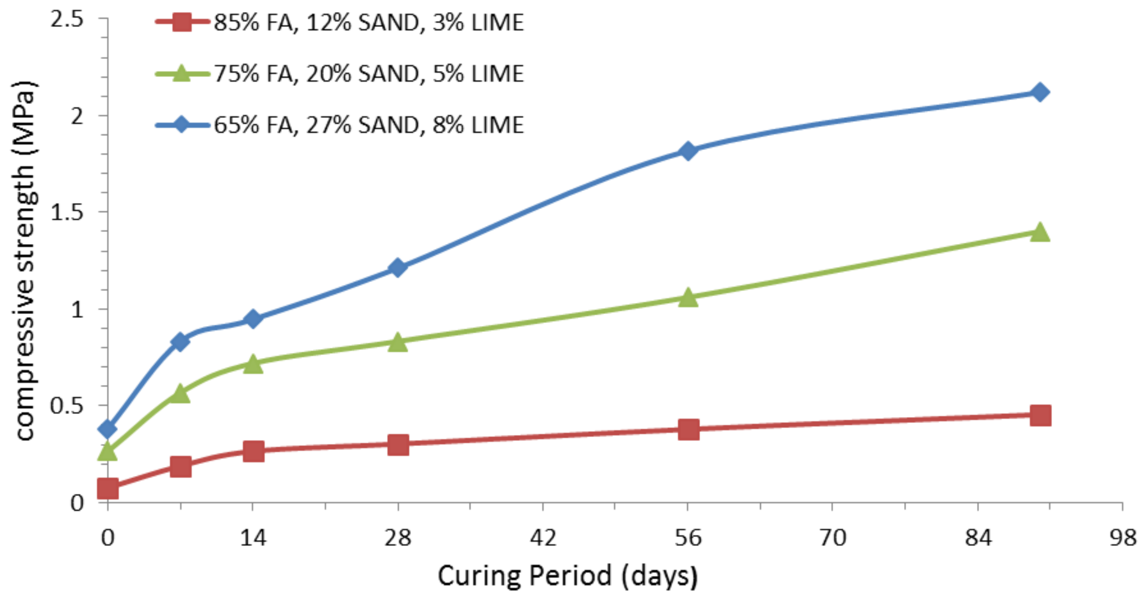

Fig. 31; Unconfined compressive strength (MPa) vs. curing periods (days)
For lime composition

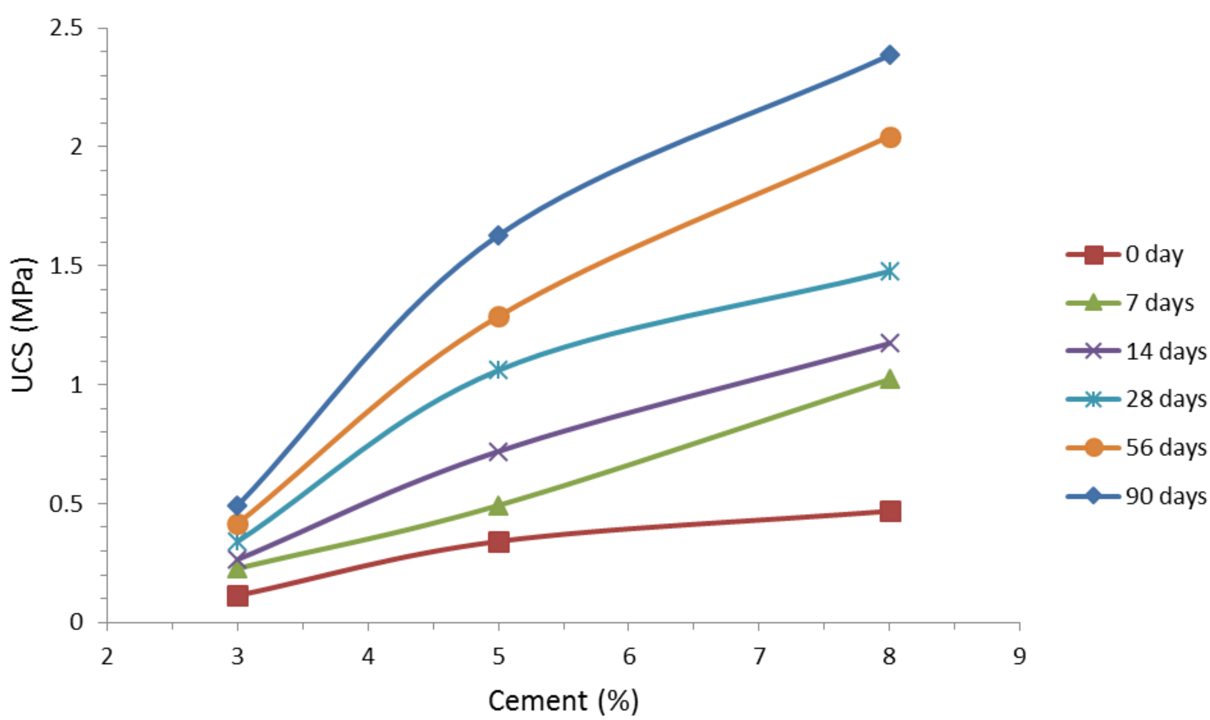

Fig. 32; Unconfined compressive strength (MPa) vs. Cement (%)

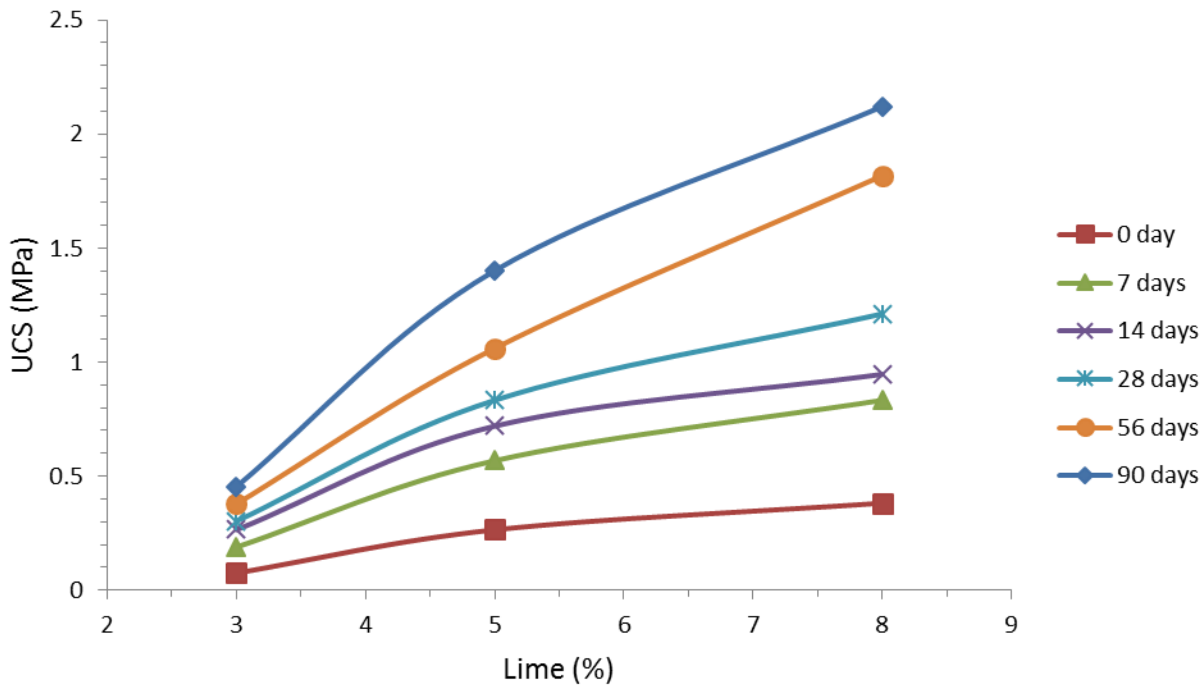

Fig. 33; Unconfined compressive strength (MPa) vs. Lime (%)

5.3.1 Young modulus:

It is observed that Young's modulus value increases as curing period increases and also with the increase in % of cement and lime. The young modulus values of all freshly prepared fly ash composite materials i.e. at 0 day is in between 2.507 to 16.936 MPa for cement composite and 2.182 to 16.623 MPa for lime. The maximum value Young modulus is 139.076 MPa of the 8% cement composition of fly ash which is more than the 103.251 MPa of the 8% lime fly ash composite material and still growing in both cases. The rate of increasing at 8% cement is the maximum between 0 to 7 days of the curing period. At 3% of cement very slow rate of increasing with the curing period. The same trend is observed for lime but in lesser magnitude. A variation of Young's Modulus with curing period, cement and lime is shown below in the graph (fig. 34 and 35).

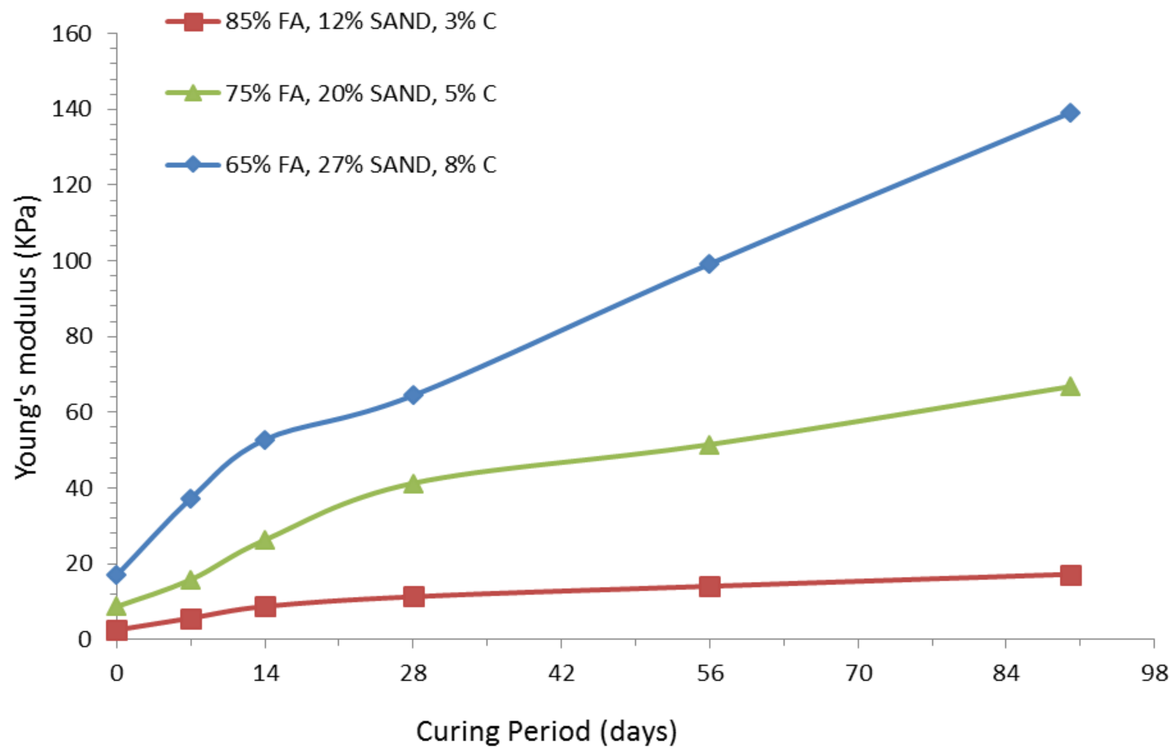

Fig. 34; Young Modulus (MPa) vs. curing periods (days) for cement composition

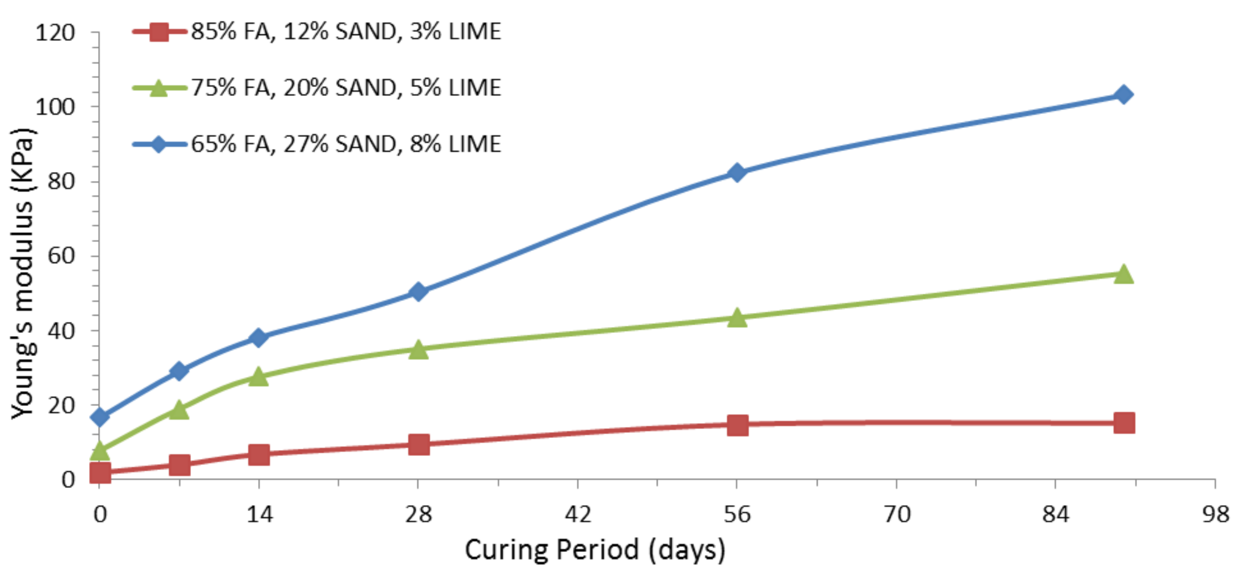

Fig. 35; Young Modulus (MPa) vs. curing periods (days)
For lime composition

5.3.2 Poisson Ratio:

It is seen that Poisson ratio obtained from the UCS test decreases as curing period increases for all fly ash composite materials signifying the development of cohesion among various constituents. The rate of decreasing is very high during 0 to 14 days of curing in all, after that it is moderate. Same trend obtained in lime composition. At 8% of cement, minimum Poisson ratio is 0.20 where as in case of 8% of lime is 0.236 (fig. 36 and 37).

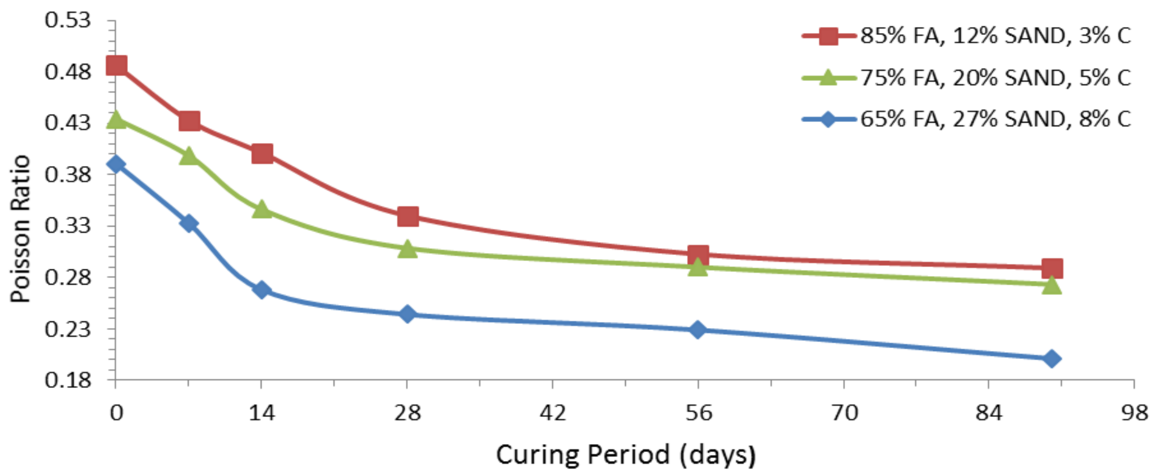

Fig. 36; Poisson ratio vs. curing periods (days) for cement composition

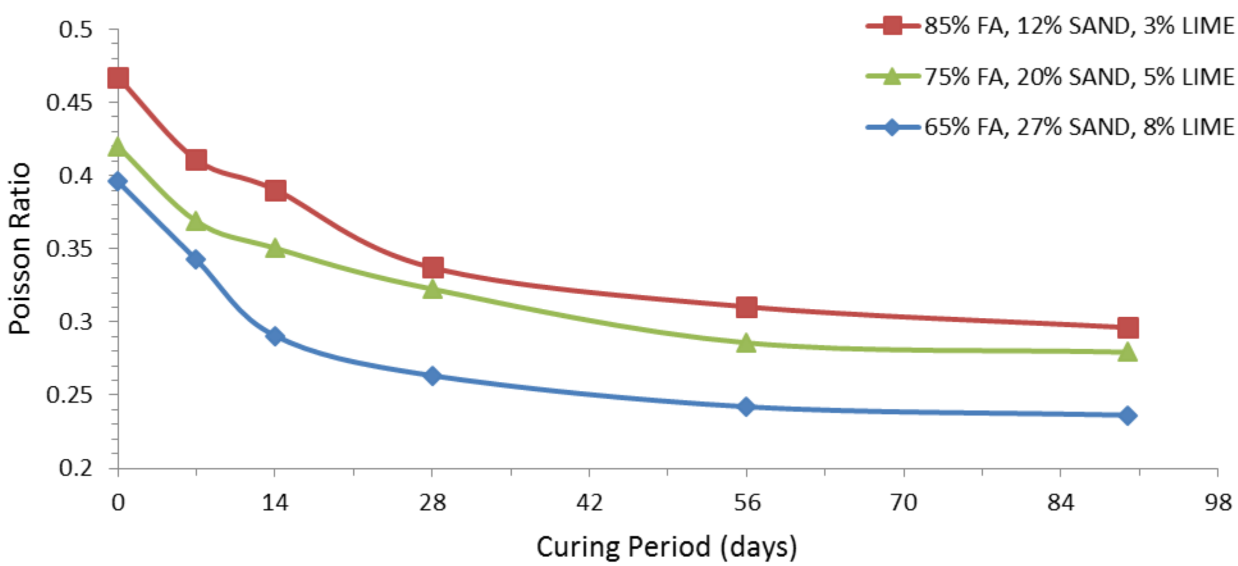

Fig. 37; Poisson ratio vs. curing periods (days)
For lime composition

5.4 Direct Shear Test:

Direct shear stress value is used as an index of material strength for the soil stabilization applications. It is observed as the % of additives and curing periods increase, shear strength of fly ash composite also increases. Main objective of doing the experiment is to know about the cohesion and friction angle of composites. Variation of cohesion and internal friction angle with respect to curing periods and additives are reported below.

5.4.1 Cohesion:

Cohesion is the ultimate internal binding force within micro-aggregates or soil particles, Calcium carbonate, as well as aluminum and iron oxide soften impart considerable stability for weak soil. It is observed that as the curing period, % of cement and lime increases, the cohesion of fly ash composite material increases. At 0 day of 3% cement composite, the valve of cohesion is 0.0054 MPa. At 0 day of 3% lime composite, the valve of cohesion is 0.0014 MPa. At 90 days of 8% cement composite, the maximum valve of cohesion is 0.2167 MPa. At 90 days of 8% lime composite, the maximum valve of cohesion is 0.1711 MPa. The relationship between cohesion, cement, lime and curing period are shown in the graph below (fig. 38, 39, 40, and 41).

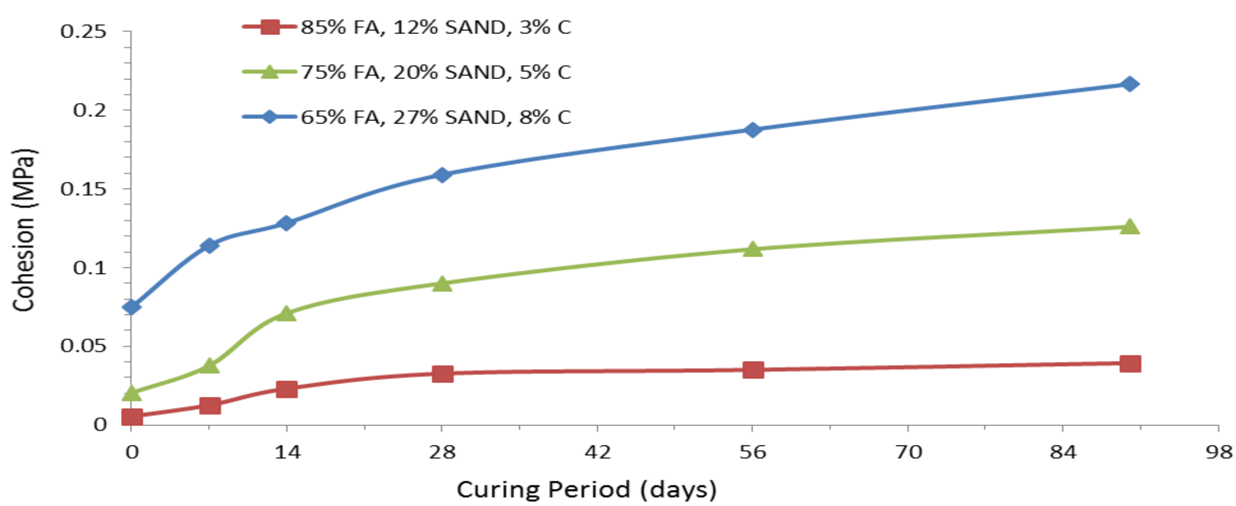

Fig. 38; Cohesion (MPa) vs. curing periods (days)
For cement composition

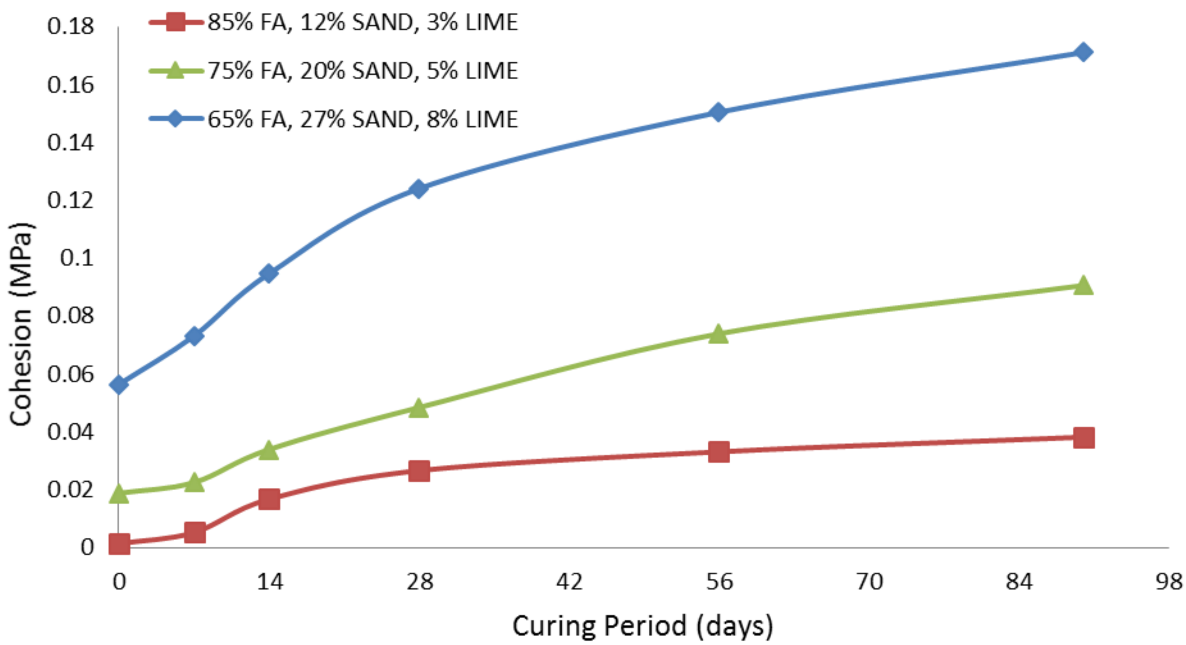

Fig. 39; Cohesion (MPa) vs. curing periods (days)
For lime composition

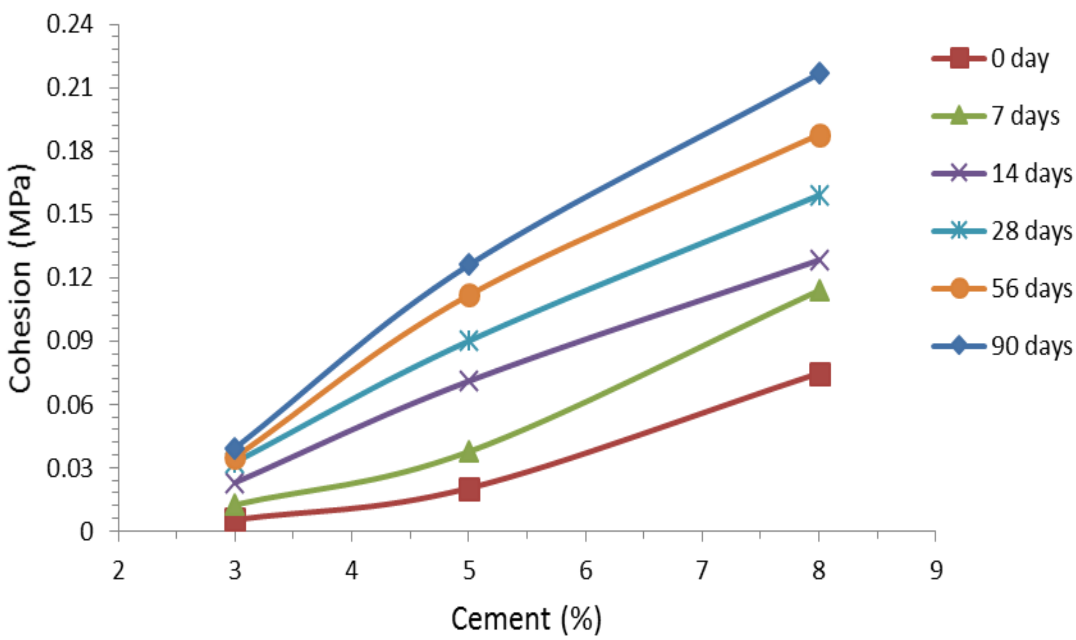

Fig. 40; Cohesion (MPa) vs. Cement (%)

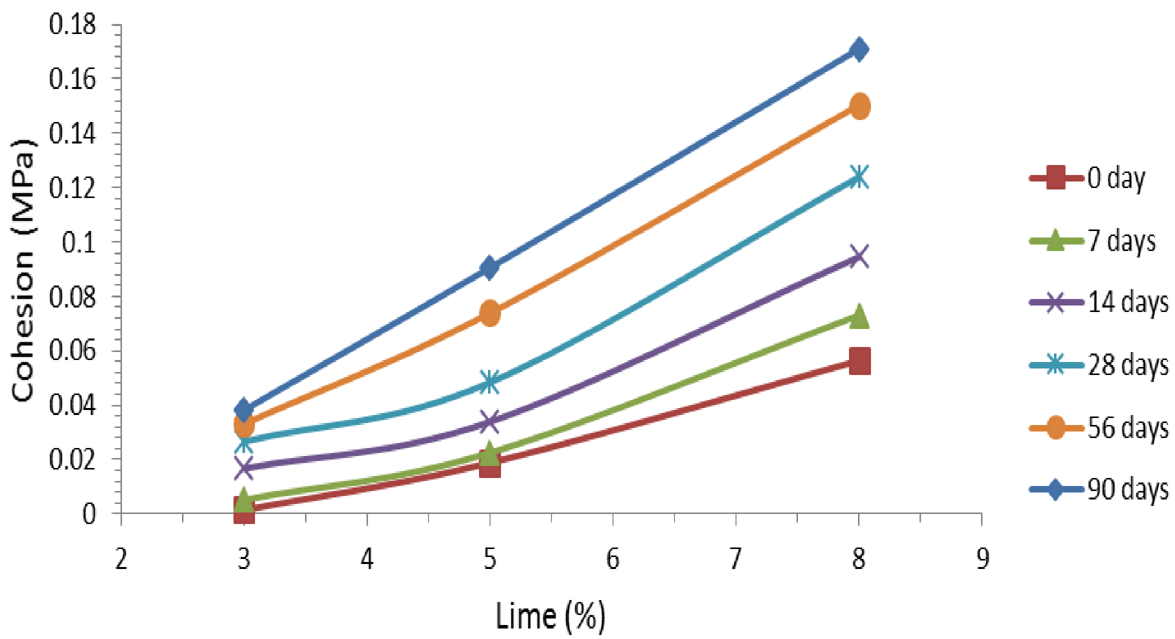

Fig. 41; Cohesion (MPa) vs. Lime (%)

5.3.2 Internal Friction Angle:

Angle of internal friction is a measure of the ability of a unit of soil to withstand applied shear loading. Lime and cement addition, increases angle of friction value of the fly ash composite materials. When the curing period is 0 day, angle of friction is 3.633^0 at 3% cement composition and angle of friction is 4.466^0 at 3% lime composition. When curing period is 90 days, angle of friction is 50.393^0 at 8% cement composition and angle of friction is 44.701^0 at 9% lime composition. The relationship between cohesion, cement, lime and curing period are shown in the graph below (fig. 42, 43, 44, and 45).

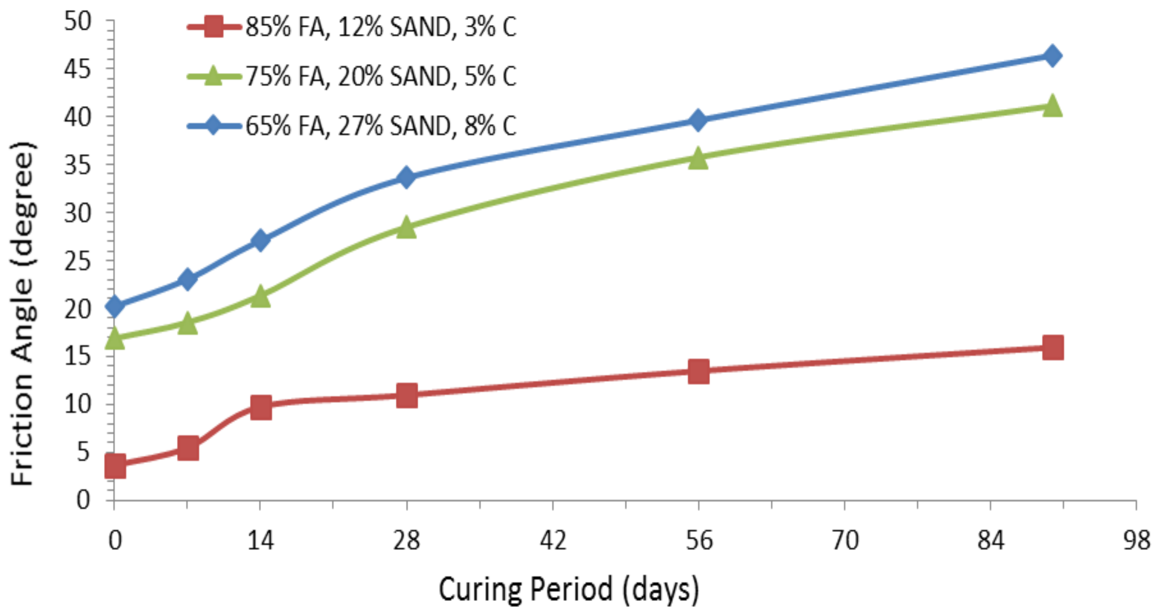

Fig. 42;.Internal friction angle (degree) vs. curing periods (days)
For cement composition

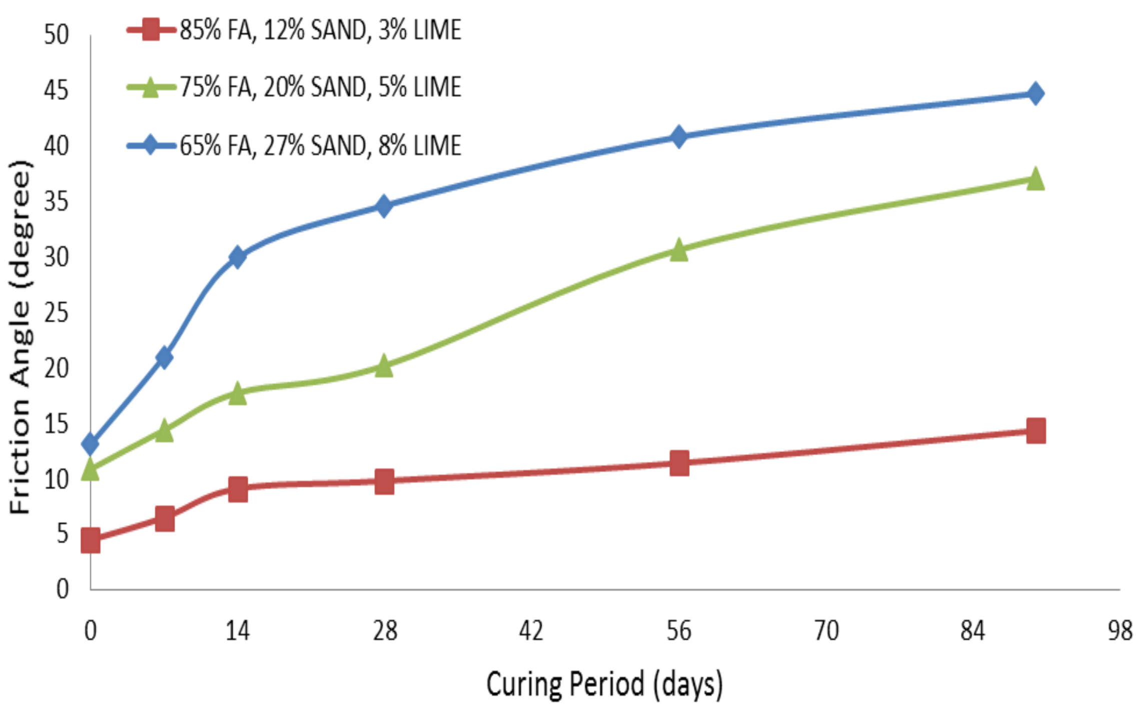

Fig. 43; Internal friction angle (degree) vs. curing periods (days)
For lime composition

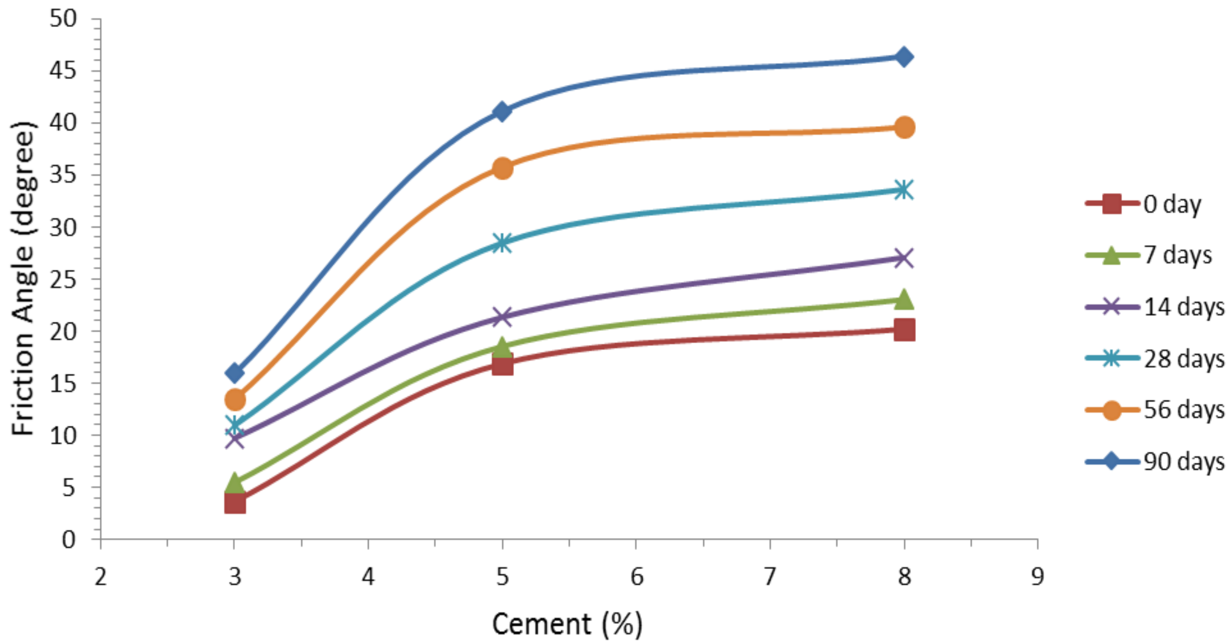

Fig. 44; Internal friction angle (degree) vs. Cement (%)

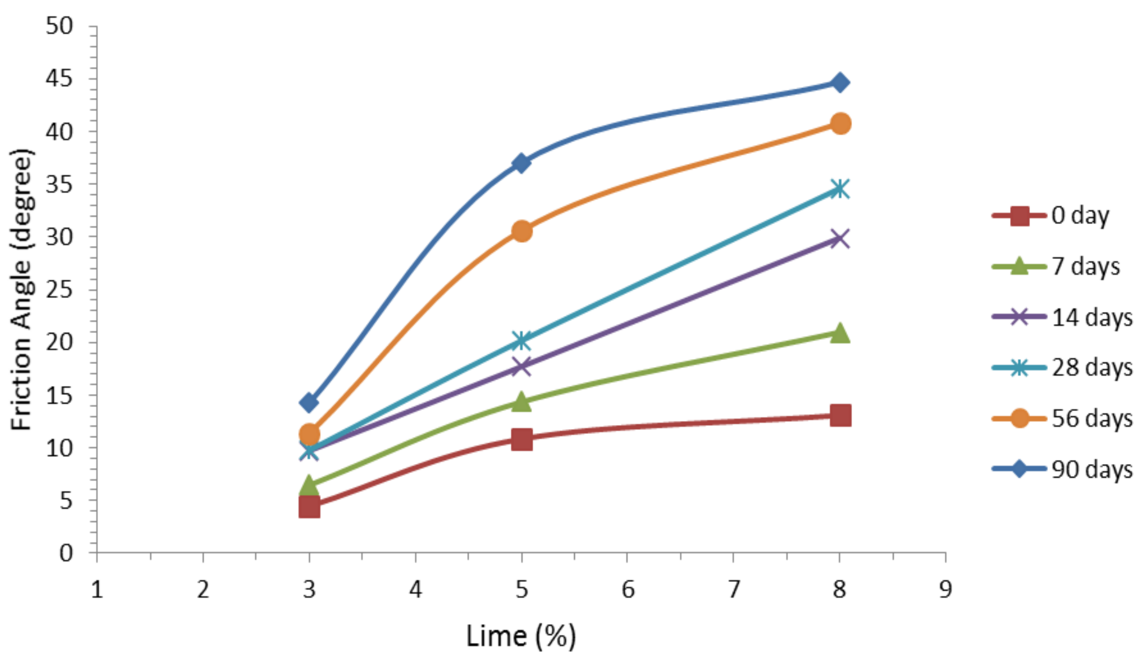

Fig. 45; Internal friction angle (degree) vs. Lime (%)

5.4 Ultrasonic Pulse Velocity:

The P-wave velocity is influenced by the quality of propagation, integral elements, dampness, occurrence of crack, voids, etc. Its precision also affected by the homogeneity of the samples. The variation of ultrasonic pulse velocities were in the range of 653 m/s to 2064 m/s for different curing periods. At 90 days of curing periods, maximum velocity values were obtained, indicting the increased conductivity in the composite samples. The conductivity is a result of enhanced pozzolanic activities due to increased reactivity of calcium oxide (CaO), alumina (Al_2O_3) and silica (SiO_2) which is a time-dependent behavior. At 7, 14, 28,56 and 90 days curing period, P-wave velocities obtained in the ranged of 653 to 1178 m/s, 906 to 1450 m/s, 1157 to 1653 m/s, 1357 to 1879 m/s and 1642 m/s to 2064 m/s respectively.

The Poisson's ratio is an important parameter of a material under loading. The Poisson's ratio values are obtained from ultrasonic pulse velocity test. The Poisson's ratio values of each composite decrease as % of cement and lime increase. The value of Poisson's ratio vay between 0.44 and 0.24 of all developed composites curing period of 0, 7, 14, 28, 56 and 90 days. The relationship between Poisson ratio, cement, lime and curing period are shown in the graph below (fig. 46 and 47).

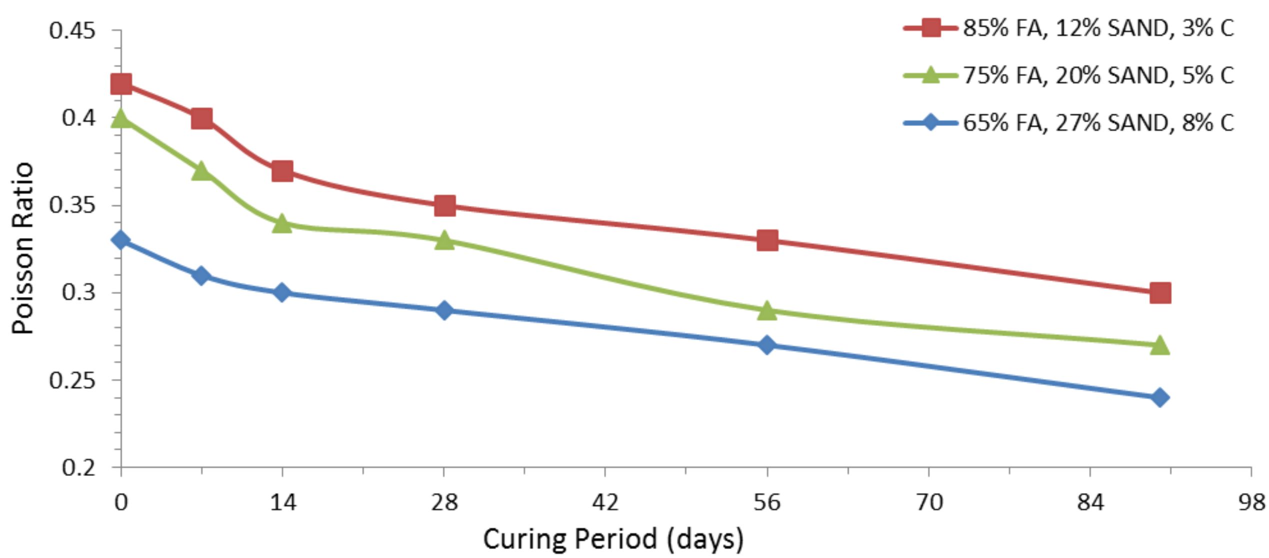

Fig. 46; Poisson ratio vs. curing periods (days)
For cement composition

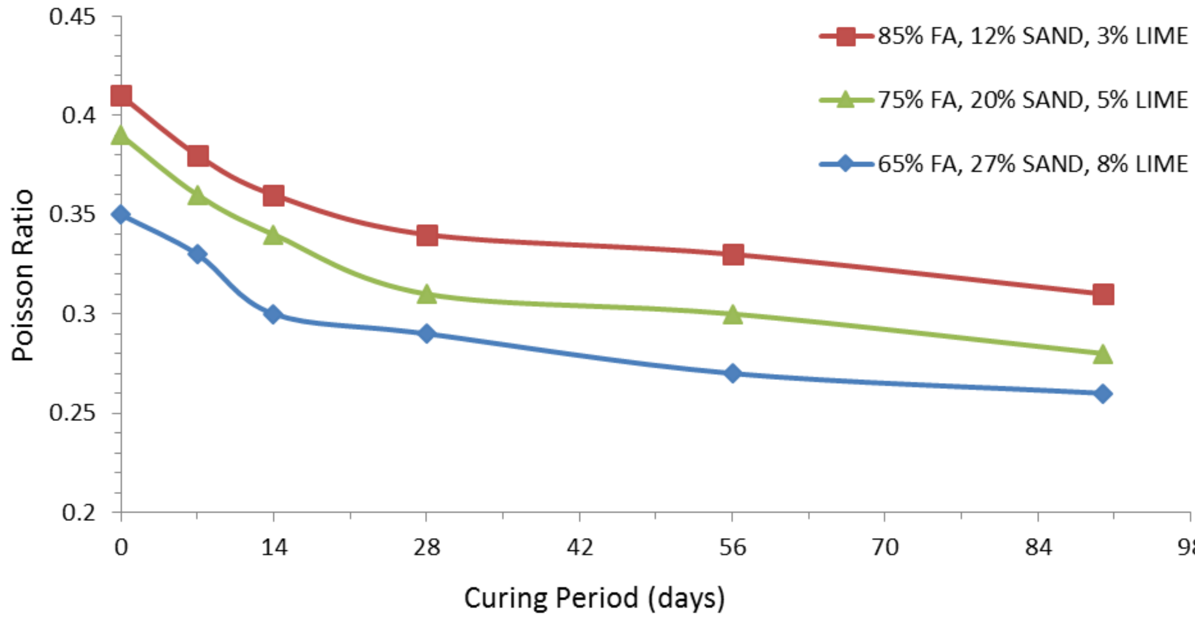

Fig. 47; Poisson ratio vs. curing periods (days)
For lime composition

CHAPTER: 6
CONCLUSION

6.1 CONCLUSIONS:

The current project was an effort to get the performance of cement and lime additives in fly ash-sand composite materials. Various fly ash based composite materials were prepared, and developed. Different experiments have been done for characterization of fly ash-based composite materials like unconfined compressive strength (UCS), Brazilian tensile strength (BTS), Proctor hammer test, direct shear test and Ultrasonic pulse velocity test. The conclusions that are come out from experiments are

1. Fly ash composite materials prepare at zero day have no any significance due to very low strength.
2. The value of Brazilian tensile strength increases with increase in cement or lime % and also increase with curing periods that goes to range of 35.635 to 197 KPa for cement additives where as in case of lime additives, it goes from 29.16 KPa to 171.7 KPa.
3. The value of Unconfined compressive strength increases with increase in cement or lime % and also increase with curing periods that goes to range of 0.114 to 2.385 MPa for cement additives where as in case of lime additives, it goes from 0.076 to 2.121 MPa.
4. Cohesion increases with increase in cement or lime % and also increase with curing periods. For additives of 8% cement, the maximum value of cohesion is 0.2167 MPa at 90 days curing period where as for additives of 8% lime, the maximum value of cohesion is 0.171 MPa.
5. Internal friction angle increases with increase in cement or lime % and also with increase in curing periods.
6. P-wave velocity increases marginally with the increase in cement or lime % and also with increase in curing periods.
7. As additives increases, the strength of the fly ash-based composite materials also increase that shows the good pozzolanic reaction.

6.2 Scope for Future:

The investigation examined different fly ash composite with cement, lime, and sand at different curing periods. It was limited by some components as time as well as other factor. However it is recommended to carry out strength evaluation beyond 90 days curing period, as well as study the influence of environmental factors in all applications

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Appendix

Proctor Hammer Test Data

Table-1: Proctor hammer reading for Fly ash-85%, sand-12% and cement-3%

Moisture content	(%)	15	20	25	30
Weight of mould,(W_1)	(kg)	3.72	3.72	3.72	3.72
$W1$+Moist. soil,(W_2)	(kg)	5.084	5.207	5.311	5.322
Weight of moist. soil,(W_2-W_1)	(kg)	1.364	1.487	1.591	1.602
Moist. unit wt.=(W_2-W_1)/10^(-3)	(kg/m3)	1.364* 10^3	1.487* 10^3	1.591* 10^3	1.602* 10^3
Mass of moisture can, W_3	(kg)	0.013	0.013	0.013	0.012
Mass of can + moisture soil,W_4	(kg)	0.027	0.032	0.03	0.028
Mass of can + dry soil,W_5	(kg)	0.025	0.028	0.026	0.023
W% = (W_4-W_5) (100)/(W_5-W_3)	(%)	16.67	26.26	30.27	45.45
Dry unit wt.=moist wt./1+(w%/100)	(Kg/m3)	1169	1177	1223	1101

Table-2: Proctor hammer reading for Fly ash-75%, sand-20% and cement 5%

Moisture content	(%)	15	20	24	27
Weight of mould,(W_1)	(kg)	3.72	3.72	3.72	3.72
$W1$+Moisture soil,(W_2)	(kg)	5.22	5.33	5.397	5.367
Weight of moist soil,(W_2-W_1)	(kg)	1.5	1.61	1.677	1.646
Moist unit wt.=(W_2-W_1)/10^(-3)	(kg/m3)	1.5* 10^3	1.61* 10^3	1.677* 10^3	1.646* 10^3
Mass of moisture can, W_3	(kg)	0.012	0.012	0.012	0.013
Mass of can+moisture soil,W_4	(kg)	0.032	0.028	0.032	0.029
Mass of can+dry soil,W_5	(kg)	0.029	0.025	0.028	0.026
W% = (W_4-W_5) (100)/(W_5-W_3)	(%)	17.65	23.077	25	33.33
Dry unit wt.=moist wt./1+(w%/100)	(Kg/m3)	1275	1308	1340	1234.5

Table-3: Proctor hammer reading for Fly ash-65%, sand-27% and cement 8%

Moisture content (%)	15	20	22	24	26
Weight of mould,(W_1) (kg)	3.724	3.724	3.722	3.72	3.724
$W1$+Moisture soil,(W_2) (kg)	5.281	5.388	5.442	5.436	5.422
Weight of moist soil,(W_2-W_1) (kg)	1.557	1.664	1.72	1.716	1.698
Moist unit wt.=(W_2-W_1)/10^(-3) (kg/m3)	1.553* 10^3	1.664* 10^3	1.72* 10^3	1.716* 10^3	1.698* 10^3
Mass of moisture can, W_3 (kg)	0.012	0.012	0.02	0.022	0.02
Mass of can+moisture soil,W_4 (kg)	0.03	0.026	0.042	0.044	0.044
Mass of can+dry soil,W_5 (kg)	0.028	0.024	0.038	0.039	0.038
W% = (W_4-W_5) (100)/(W_5-W_3) (%)	12.5	16.67	22.22	26.33	33.33
Dry unit wt.=moist wt./1+(w%/100) (Kg/m3)	1380.4	1427.9	1407.9	1358	1273.5

Table-4: Proctor hammer reading for Fly ash-85%, sand-12% and lime 3%

Moisture content (%)	17	21	25	29
Weight of mould,(W_1) (kg)	3.688	3.688	3.686	3.688
$W1$+Moisture soil,(W_2) (kg)	5.11	5.216	5.292	5.256
Weight of moist soil,(W_2-W_1) (kg)	1.422	1.528	1.606	1.568
Moist unit wt.=(W_2-W_1)/10^(-3) (kg/m3)	1.422* 10^3	1.528* 10^3	1.606* 10^3	1.568* 10^3
Mass of moisture can, W_3 (kg)	0.022	0.022	0.02	0.012
Mass of can+moisture soil,W_4 (kg)	0.04	0.038	0.042	0.32
Mass of can+dry soil,W_5 (kg)	0.037	0.035	0.037	0.027
W% = (W_4-W_5) (100) /(W_5-W_3) (%)	20%	23.07	29.4	33.33
Dry unit wt.=moist wt./1+(w%/100) (Kg/m3)	1186.4	1241.5	1242.6	1173.2

Table-6: Proctor hammer reading for Fly ash-75%, sand-20% and lime 5%

Moisture content (%)	15	20	24	28
Weight of mould,(W_1) (kg)	3.688	3.688	3.688	3.689
$W1$+Moisture soil,(W_2) (kg)	5.174	5.306	5.327	5.32
Weight of moist soil,(W_2-W_1) (kg)	1.486	1.618	1.639	1.631
Moist unit wt.=(W_2-W_1)/10^(-3) (kg/m3)	1.486* 10^3	1.618* 10^3	1.639* 10^3	1.631* 10^3
Mass of moisture can, W_3 (kg)	0.012	0.012	0.013	0.022
Mass of can+moisture soil,W_4 (kg)	0.03	0.03	0.03	0.05
Mass of can+dry soil,W_5 (kg)	0.028	0.027	0.027	0.044
W% = (W_4-W_5) (100)/(W_5-W_3) (%)	12.5	20	21.43	27.27
Dry unit wt.=moist wt./1+(w%/100) (Kg/m3)	1320	1304	13497	1281

Table-6: Proctor hammer reading for Fly ash-65%, sand-27% and lime 8%

Moisture content (%)	15	20	24	28
Weight of mould,(W_1) (kg)	3.688	3.688	3.688	3.689
$W1$+Moisture soil,(W_2) (kg)	5.248	5.402	5.352	5.281
Weight of moist soil,(W_2-W_1) (kg)	1.56	1.714	1.664	1.592
Moist unit wt.=(W_2-W_1)/10^(-3) (kg/m3)	1.56* 10^3	1.714* 10^3	1.664* 10^3	1.592* 10^3
Mass of moisture can, W_3 (kg)	0.02	0.022	0.012	0.022
Mass of can+moisture soil,W_4 (kg)	0.038	0.042	0.032	0.044
Mass of can+dry soil,W_5 (kg)	0.035	0.038	0.027	0.037
W% = (W_4-W_5) (100)/(W_5-W_3) (%)	20	25	33.3	46.67
Dry unit wt.=moist wt./1+(w%/100) (Kg/m3)	1300	1371.2	1251.3	1084